Bell Telephone

RADAR:

Radar and Bell Laboratories • MERVIN J. KELLY

Radar: A Story in Pictures

Radar and Western Electric • FREDERICK R. LACK

The Bell System's First Order of Business • HAROLD S. OSBORNE

Dual Telephone Service Ends in Philadelphia • PETER L. SCHAUBLE

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Winter 1945-46

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"The ideal and aim of the American Telephone and Telegraph Company and its Associated Companies is a telephone service for the nation, free, so far as humanly possible, from imperfections, errors, or delays, and enabling anyone anywhere to pick up a telephone and talk to anyone else anywhere else, clearly, quickly and at a reasonable cost."

A Medium of Suggestion & a Record of Progress

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WALTER S. GIFFORD, *Pres.;* CARROLL O. BICKELHAUPT, *Sec.;* DONALD R. BELCHER, *Treas.*

Who's Who & What's What

in This Issue

HISTORIANS OF World War II will record that the armed might of the Allied Nations had laid Italy and Germany prostrate and was closing in on Japan for the kill before Manhattan Project's atomic secret burst on the world; and they may attribute those military successes in no small part to the advantage the Allies possessed in radars of many kinds, vast numbers, and superior performance.

The Bell System had a large and important share in the development and production of radar in this country. How large, how important, is now recounted comprehensively for the first time by two men who speak with authority and from an intimate knowledge of the radar program:

MERVIN J. KELLY

MERVIN J. KELLY, executive vice president and a director of Bell Telephone Laboratories; and FREDERICK R. LACK, vice president and a director of the Western Electric Company and head of its Radio Division.

Joining in 1919 the Engineering Department of Western Electric—which became Bell Laboratories in 1925—Dr. Kelly has devoted the years since to research in electronics and to the development of many types of thermionic devices. He was appointed director of research of Bell Telephone Laboratories in 1936, and in 1944 he was given additional responsibility as

FREDERICK R. LACK

executive vice president. During World War II he devoted practically all his time and energy to the Laboratories' multitudinous war projects, and was in particularly close touch with the progress of radar.

Mr. Lack joined the Manufacturing Department of Western Electric in 1911. A year later he transferred to the Engineering Department, and to it he returned in 1919 after overseas service in World War I. Thereafter his work was concerned broadly with the development of several aspects of radio telephony, including the use of piezoelectric crystals for stabilizing radio frequency generators, and vacuum tubes for various types of radio telephone application.

Mr. Lack left Bell Laboratories in 1938 to return to Western Electric as commercial manager; and in 1942 he was elected vice president and was appointed manager of the Radio Division. At the Government's invitation, he served for some months during 1942 and 1943 as director of the Army and Navy Electronic Production Agency.

IN THE past five years this MAGAZINE has recorded some of the many ways through which the Bell System contributed to this country's share in victory over the Axis Powers. The contributions were major and the effort was extreme—as witness, for example, this issue's articles on radar. But now "the war is over" to most people—including a good many who want telephone service, haven't been able to get it, and don't see why not. So, having performed near-miracles of many kinds under the stress of war, the System recognized that to accomplish still other miracles became its first order of business under the stress of peace; and HAROLD S. OSBORNE submits a report on "how we're doin'," and how we are doing it. He joined the A. T. & T. Co. in 1910 as an engineer in the then transmission and protection department, and has since been transmission engineer, operating results engineer, plant engineer, assistant chief engineer, and—since 1943—chief engineer of the present Department of Operation and Engineering. He was co-author of "More and Better Telephone Service for Farmers," which appeared in the Winter issue of this publication a year ago.

HAROLD S. OSBORNE

ELIMINATION of the Keystone Telephone Company from the Philadelphia scene does indeed mark the end of an era—but an era for which there need be no regret, no nostalgia for the good old days. The days of competitive telephone service were not good: duplicative service was always uneconomic and a nuisance. And since the country finally got rid of it, for all practical purposes, at Philadelphia last September 17, it is PETER L. SCHAUBLE who tells how its end came about. For he is vice president of the Bell Telephone Company of Pennsylvania in charge of the Public Relations

PETER L. SCHAUBLE

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AIR EXPRESS was the fastest method of getting telephones to certain areas where shortage of instruments alone was delaying service to waiting customers—so by air express they went. See "The Bell System's First Order of Business," page 295

The Bell System's Development and Huge Production of Many Kinds of Radars Rank High as a Contribution to The Victories Over the Axis Powers

Radar and Bell Laboratories

Mervin J. Kelly

RADAR—RADIO DETECTION AND RANGING—in the importance of its contribution to victory ranks high among the new weapons of World War II. It employs radio waves for the detection and accurate location of objects, fixed or moving. It can see farther than the eye, even under conditions most favorable to vision. It sees equally well by night and by day. Neither smoke, fog, clouds, nor rain diminishes its range or its resolution of objects.

Radar refers to no single instrument: it is a synthetic word which describes a function. Indeed, an individual radar set may weigh only a hundred pounds, have the size and shape of a small bomb, and be suited to installation in a fast airplane; or it may be a vast assemblage of equipment mounted in a truck and several trailers, have a giant antenna structure, and require a whole company of soldiers to operate it. It may be a three-ton equipment disposed above and below the deck of a battleship, or it may be two or three water-tight boxes on the deck and a small antenna on the mast of a landing barge. While radars assume this great variety of form and size, they are all governed by the same radio principles and employ the same electronic and communication techniques. Their functioning elements have, in common, electron tubes in large number and great variety, interconnected by most complex communication-like circuits.

All radars embody a transmitter, an antenna, a receiver, and a video system. The transmitter generates the radio energy as pulses of suitable form and power. The antenna both radiates energy in a preferred space pattern and picks up energy "echoed" from the objects viewed. The receiver accepts from the antenna the returning pulses of energy and ampli-

fies and reshapes them in such a way that the video system can display the echo information in a variety of visible patterns and supply it in electrical form for the direction of missiles.

IN CONSEQUENCE of its ability to see, radar played a great and increasingly important role in the conduct of the war on land, at sea, and in the air. It has brought about profound changes in the pattern of warfare. Surprise has always been one of the most important elements in attack. In the past, surprise has been achieved by the deployment of forces in the darkness of night or under a covering of fog, cloud, or smoke. The early warning of enemy approach afforded by our ever-improving radar equipments and the increasingly effective techniques for their use deprived the enemy of the advantage of surprise attacks.

Radar not only sees; it can also measure distance and angles. Radar continuously measures the distance to a fixed or moving object and the angles defining the direction of the object with such exactness that this location information can be used for fire control of guns, directing of torpedoes, or dropping of bombs.

A new instrument of war, when equally developed and applied by the combatants, changes the style of war but is not likely to become a decisive element in victory for either side. However, when one of the combatants moves more rapidly in the development of the new instrument and makes broader and more rapid use of it in his strategy of war, he then can make it an important and perhaps determining element in his victory. This, indeed, is the pattern of radar's application in World War II.

In the years immediately before the war, radar was conceived and had its pioneering development in the military laboratories of our country, England, Germany, and perhaps Japan.

At the war's beginning, the radar technologies of Germany, England, and our country were at about the same level of development, while Japan's was decidedly inferior. As the war progressed, we advanced radar science with much greater speed than did our enemies. We applied it to almost all sectors of warfare, and supplied our armed forces with a tremendous volume of specialized equipments suited to a wide variety of applications. Our armed forces made immediate and broad application of this radar equipment and modified their strategy of war to great advantage as they increased their facility in the use of this new weapon.

Our enemies, advancing the technology at a slower pace, made available to their armed forces a substantially smaller volume of equipments which were more limited in variety and of a lower level of effectiveness.

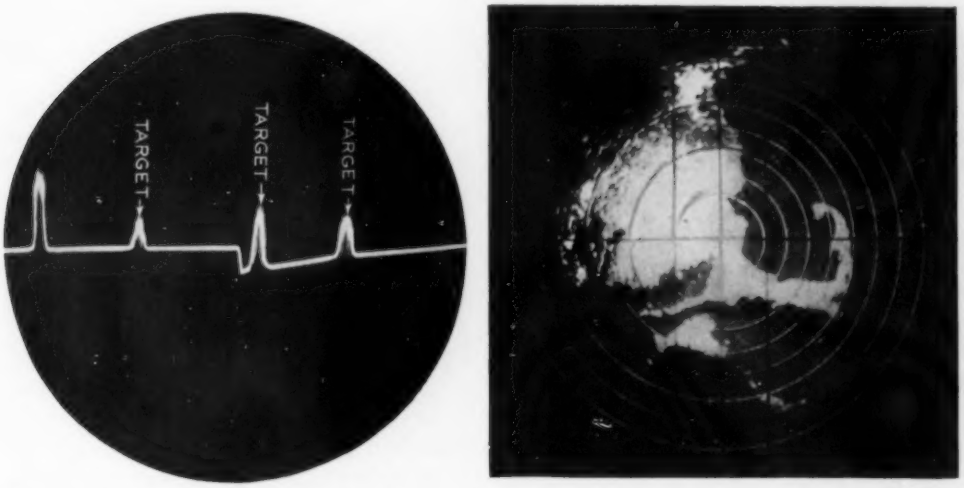
As the war progressed, radar, therefore, became an instrument of increasing advantage to us. It shortened the war and made our victory possible at a lower cost in lives and material.

RADAR ATTAINED this high level of importance to victory because our country concentrated on it a gigantic effort in research, development, design, and production. In 1940 less

than $25,000,000 was expended on technical and production effort for radar. Radar effort in all its phases expanded rapidly throughout the war, and in 1945 was at an annual level of more than $1,000,000,000.

There have been many technical workers in this field both in England and in this country. They have enjoyed full interchange of technical information, so that each could use the information of the other as well as his own. In particular, Bell Laboratories worked very closely in this field first with Army and Navy laboratories and later also with the Radiation Laboratory at Massachusetts Institute of Technology; and in all cases there was freest interchange of technical material.

The laboratories of the Services were working in radar through the 1930s. When, in 1940, the national defense program was materially stepped up, the National Defense Research Committee set up the Radiation Laboratory at Massachusetts Institute of Technology to undertake a broader program of Government-sponsored research than had been possible with the limited facilities of the Services' laboratories. This organization built up its research staff and facilities and carried out a most important program of research and development work, particularly in the micro-wave field.



RADAR ECHOES are displayed on an oscilloscope screen. The "A" presentation (left) shows the distance to three targets; the "PPI" (right) gives a map-like picture of the area below an air-borne radar—here the Cape Cod area of Massachusetts

The Bell System played a larger part in the radar program, from research through production, than any other industrial organization. Through its manufacturing company —the Western Electric—it produced about half of all the radar made in the United States; and through its research organization—the Bell Tele-

phone Laboratories—it carried out a comparable portion of the research and development programs.

Throughout the preparedness and war years, the Laboratories, with a continuously expanding program, gave almost half of its effort to radar science and technology. It expended approximately $85,000,000 in its research, development, design, and early-model production effort.

The Western Electric Company produced equipments resulting from this effort in a volume of approximately $900,000,000, and there was production of radar facilities by others, from designs completed in Bell Laboratories, in volume of at least $100,000,000.

Radar's Early History

RADAR, THROUGH ITS receiver and video system, determines the distance to each object by measuring the time required for a pulse of radio energy generated by its transmitter to go from its antenna to the object and to return. (The pulse is reflected or "echoed" by the object.) The object's direction is determined by observing the direction in which the antenna is pointing when it receives the maximum energy from the object. (The antenna points directly at the target when it receives the maximum energy return.)

Man has long had the desire to see in darkness and through fog. But the satisfaction of this desire had to await the development of radio technology to a degree first reached at the beginning of the 1930s, when the techniques and tools essential to the pioneering development of object location with radio waves were at hand. We now know that those engaged in military radio research in Germany, England, and our own country turned their attention to this development at about the same time.

Many elements of new technology were necessary. Probably the most important were the extension of the useful radio spectrum to wave lengths at least as short as two or three meters; advances in electronic and circuit techniques to make possible generation of extremely short pulses of radio energy at high levels of power; and accurate measurement of time intervals as short as a few hundred-millionths of a second.

Making use of these new elements of technology as well as of established communication and electronic art and science, our Army and Navy laboratories made remarkable progress during the 1930s in evolving research models of object-location equipment using radio waves. Behind the cloak of secrecy essential to military research, they studied various radio methods of object viewing, and selected the preferred system by the middle of the 1930s. They then worked intensely, within the limits of their resources, to improve and perfect the system selected. The Naval Research Laboratory pointed its effort to equipments for use on ships,

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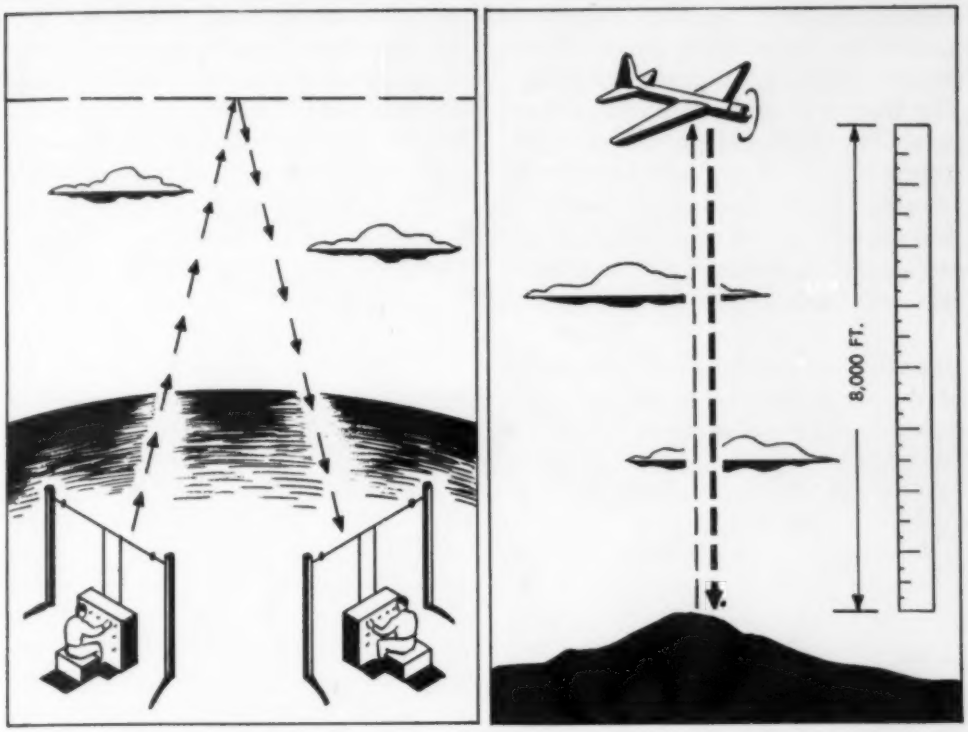
RADAR may well be considered a type of radio communication. It is like broadcasting in that it is one-way transmission of intelligence. It is unlike broadcasting in that it gathers intelligence from its surroundings rather than giving it out. The intelligence gathered is the distance and direction of objects within the range of the radar.



RADAR DEVELOPMENT by Bell Laboratories was greatly facilitated by earlier experience with such projects as measurement of the height of the ionosphere (left), and the radio altimeter (right), both employing the echo technique

while the Fort Monmouth Signal Corps Laboratory directed its attention to equipments for army ground forces.

ON JULY 13, 1937, at the invitation of Commander (now Captain) W. G. Ruble, some Bell Laboratories engineers, accompanied by Commander (now Commodore) J. B. Dow, visited the Naval Research Laboratory at Anacostia, and were shown the radar work which was in progress there under the immediate direction of Dr. A. H. Taylor. After this visit, as is Bell Laboratories' practice at the preliminary survey stage of any new research program, an analytical study and appraisal were made. A selected group of scientists and engineers made an analysis, as complete as was possible with available information, of object location through the use of radio waves. This included re-radiation (echoing) from targets, and the advantages and limitations of different ranges of the radio frequency spectrum. The Bell Laboratories group returned to the Naval Research Laboratory on November 5, 1937, to witness a demonstration of improvements which had been made in the meantime and for further discussions with those working on the project.

The men at the Naval Research

Laboratory were working with wave lengths in the neighborhood of one to two meters. They were transmitting from a directional antenna short pulses of radio energy in this wavelength range. They had already developed an ingenious circuit for using the same antenna for sending the radio pulses and receiving their echoes reflected from objects in the vicinity.

BECAUSE OF fundamental properties of the wave lengths employed, their system had only limited—though important—military value. It was adequately effective for military use only against airplanes flying at relatively high altitudes. At the wave lengths employed, it is not possible to get enough energy on and immediately above the surface of the sea to detect ships or low-flying planes with a certainty and over distances essential to military value.

In spite of these restrictions, which are fundamental to the wave lengths employed, the Naval Research Laboratory's object location system was a most important development. It incorporated fundamental principles, essential circuits, and electronic techniques which were to characterize the enormous radar developments of the following years. Although, as the war progressed, radars using shorter waves came to play a larger part in our radar warfare, this early system established in wave length and in circuit arrangement the pattern for the large number of equipments which were used by our naval ships of many classes throughout the war for the longest-range detection of enemy planes.

The Naval Research Laboratory's scientists and those from Bell Laboratories recognized the limitations of the wave lengths employed and were in agreement that considerably shorter wave lengths were essential to the location of low-flying planes and of objects, such as ships and submarines, on the surface of the water. They also recognized that, with materially shorter wave lengths and further advances in circuit and electronic techniques, beams of radio energy could be made sufficiently pencil-like in nature (similar to a searchlight beam) to distinguish objects separated by small distances, such as planes flying in formation, and to measure the exact distance and direction to one of them. Shorter wave lengths could extend the area of radar's application down to the surface of the sea and, through adequate resolution and accurate measurement of object position, make radar direction of gun fire possible. Shorter radio waves must be used in radar!

Bell Laboratories' First Radar Project

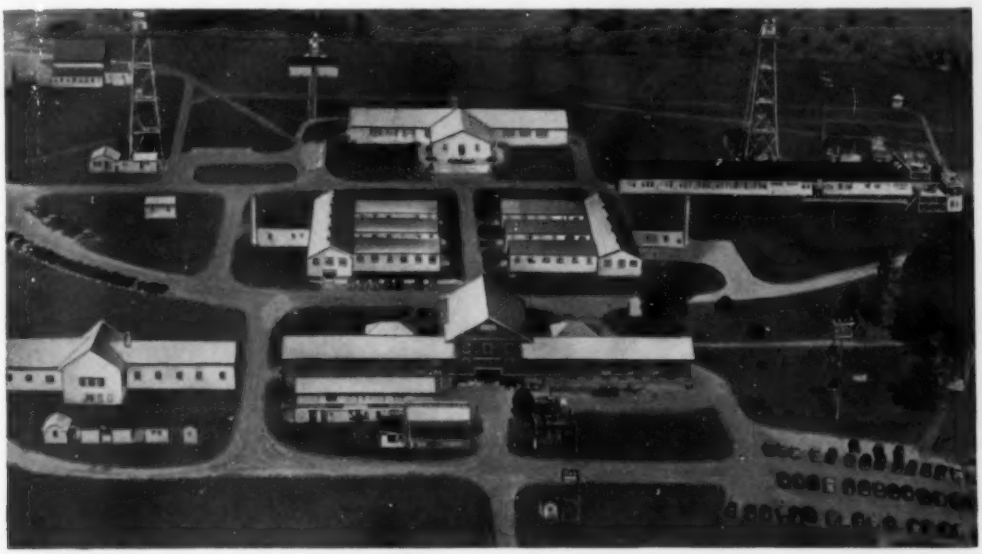
THERE WAS already in progress at Bell Laboratories a research program directed at the extension of the radio spectrum to shorter and shorter wave lengths. This was a part of the Bell System's program of extending the scope, improving, and lowering the cost of communication through new applications of science.

The group at Bell Laboratories who had been brought into the radar secret believed that communication circuit techniques and new electronic devices then available from this research program were adequate for the initiation of explorations in radar to a wave length as short as perhaps 40 centimeters (16 inches).

After discussions between Bell Laboratories' management and those responsible in the Bureau of Ships, it was agreed that the Laboratories, because of its knowledge and experience in this field, could be of most service to the radar development program in extending radar to shorter wave lengths.

The radar excursion into the shorter wave-length area, which even for communication was in the research stage, was of such a pioneering and speculative nature that it was not possible to predict that any useful military equipment would result. Under the then established rules of Navy development contracts, it was not practicable to contract for such a highly speculative research program. However, all concerned recognized the importance of such an investigation.

Because of its potentialities for results of importance to our country's preparedness program, and because of the intimate relation of Bell Laboratories' centimeter-wave radio research to the centimeter-wave radar problems, the American Telephone and Telegraph Company authorized the Laboratories to proceed with the investigation. This made it possible for the Laboratories to carry the radar excursion into the shorter wavelength area to a place where, if successful, contracts could be entered into with the Navy for a development to specified requirements.



RADAR DEVELOPMENT in the Bell System was centered at the Whippany plant of Bell Laboratories. Rapid wartime growth required construction of many temporary buildings

The allocation of funds that made it possible for Bell Laboratories to initiate at such an early date a re-

search program extending radar into the centimeter range started a chain of events which was to be of profound significance in our country's naval victories and in its radar development programs.

As will later be revealed, Bell Laboratories' radar activities in the 40-centimeter area which resulted from this research were of importance not only in making the first fire-control radars available but also in bridging the gap between the early radar work of our Army and Navy laboratories and the ten-centimeter and shorter wave-length radar programs which were initiated in 1940.

> HAD THE LABORATORIES *not proceeded immediately with this research —carried out without the restrictions of a specifically directed contract— fire-control radar would probably not have been in production and installed on some of the ships of our fleet by the time of the Japanese attack on Pearl Harbor. The night victories of the South Pacific in the winter of 1942–1943 which our outnumbered fleet won through radar search and radar-directed gun fire might well have been defeats.*

Soon after the November 5, 1937, visit to the Naval Research Laboratory, work was begun in Bell Laboratories on its centimeter radar program. In May, 1938, the research was moved from its New York location to the laboratory at Whippany, New Jersey, the better to maintain secrecy and to facilitate object location experiments.

Throughout the remainder of 1938 and in the Spring of 1939, the Whippany group continued its intensive program of application of centimeter waves to radar. It received support in essential research and development from various component groups in Bell Laboratories. By early Summer of 1939 the first research model of a complete radar equipment operating at about 60 centimeters had been completed and had been given, as far as possible at Whippany, object location tests, principally against planes. To obtain better information about its performance under location conditions equivalent to those on a ship, a bungalow to house the equipment was obtained at Atlantic Highlands on a bluff whose height above the water approximated that of an antenna installed atop a battleship.

This site proved so satisfactory for tests of ship-borne radars that Bell Laboratories later built a test house on land adjacent to the bungalow. It was in use continuously throughout the war in testing early research and development models. These tests were frequently witnessed by radar scientists and interested military personnel of our country and our Allies.

The usual sequence of events on the development model of a new equipment was to complete its assembly and "tuning up" at Whippany, then to make performance tests and adjustments at the Highlands test house. When the equipment was found to meet the Navy's performance requirements, it was taken to the Naval Research Laboratory for final evaluation.

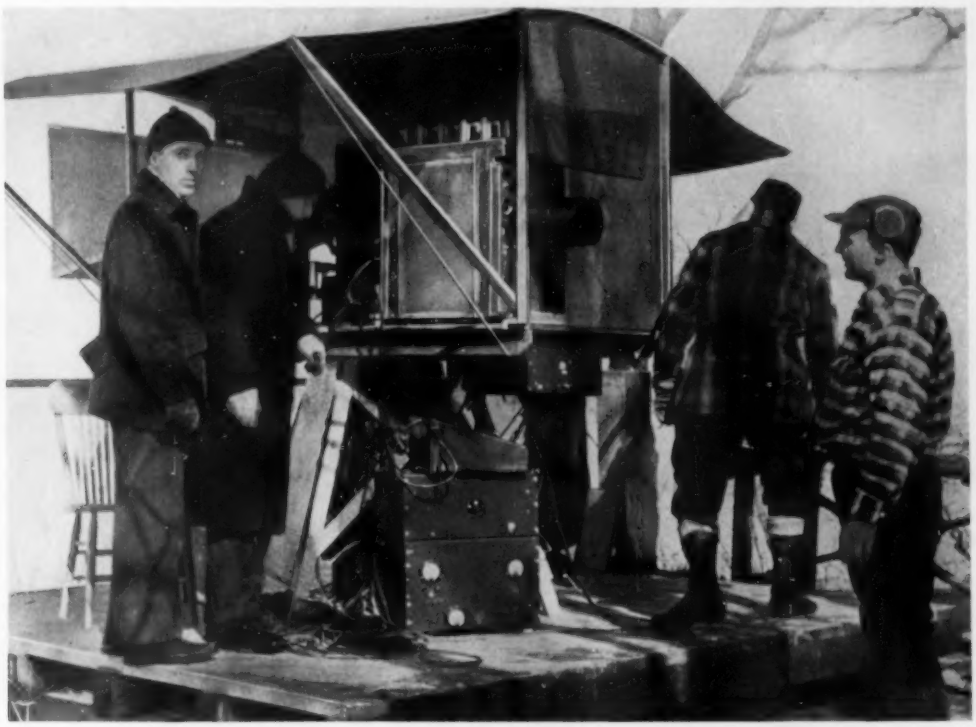
Successful performance tests of the new equipment were made here in June, 1939. At that time sharp and stable echo signals were obtained from nearby ships, from buildings on

Sandy Hook, and from gas tanks in Brooklyn—some twenty miles distant. Testing and improvement continued throughout the summer, and demonstrations of the equipment's operation were given to interested Service personnel during this time.

Adequate knowledge was now available from the research to permit undertaking the development of a radar equipment to meet specified performance requirements. The Western Electric Company entered into a contract with the Navy for the Bell Laboratories' development of such an equipment for ship search and location. The equipment was given the code CXAS by the Navy. The laboratory work on the Navy project began December 31, 1939.

In order to test the relative effectiveness of different centimeter waves, the equipment was so made that tests could be made at wave lengths in the range from 60 to 40 centimeters. The equipment developed under the contract was demonstrated to the Navy at the Atlantic Highlands laboratory during December 1940.

These tests indicated the superiority of the 40-centimeter wave length,

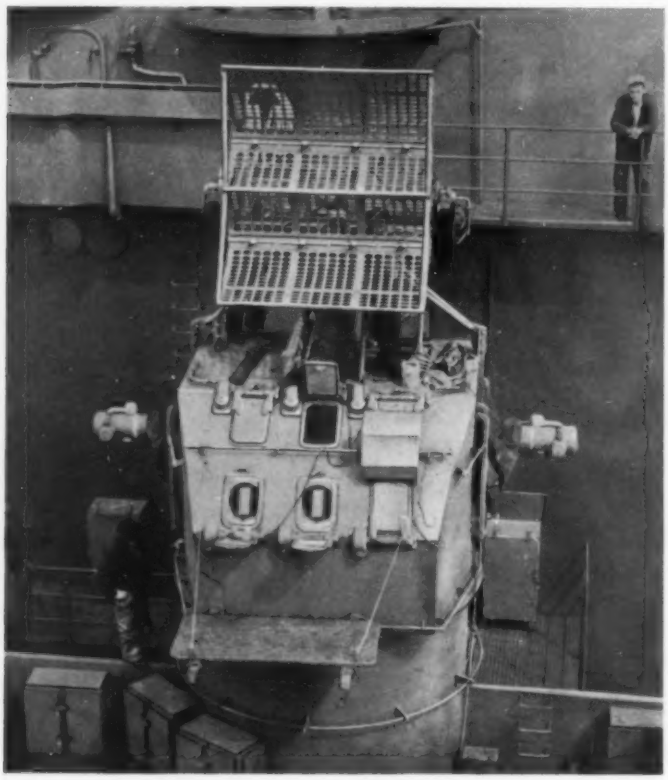


A TYPICAL SCENE on the grounds of the Atlantic Highlands laboratory, where many tests of development models were carried out

and it was adopted for the first equipments to be standardized. Soon after the conclusion of these tests the Navy authorized the design-for-production for fleet use of two equipments which later were coded Mark 3 and Mark 4.

with sufficient accuracy to control gun fire. These were probably the first radar equipments anywhere which delivered complete fire-control data of sufficient accuracy for use in battle.

The urgency was so great that Western Electric was authorized to proceed with manufacture with all possible speed. As soon as the design of an element of the equipment was completed, Western placed it in manufacture. In that way production began within a few months of completion of design. The Laboratories made performance tests on its



ANTENNA of the pioneering Mark 4 anti-aircraft set, installed on the battleship Tennessee

The Mark 3 was for use only against surface targets, such as ships or submarines, as it could only "track targets" in the horizontal plane. The Mark 4 was for use against either surface targets or planes in flight. Both radars delivered complete fire-control data—range and angular position—

first Mark 3 design model in July of 1941, and Western delivered the first production model in October. Tests were made on the first Mark 4 design model in August, and Western's first delivery was in December.

Both equipments were in production and some had been installed on Navy vessels before Pearl Harbor was attacked. Hundreds were to follow during the next year. The Navy was dependent upon them for its radar fire control in all of its engagements of the next fifteen months. The Japanese radar, at best, was feeble and too inaccurate to serve for fire control. This element of technical superiority was a most important factor in our night-time naval victories in the South Pacific in the Winter of 1942–1943.

These radars controlled the cruiser Boise's guns in October, 1942, when she blazed away at night at a vastly superior fleet in the Solomons and made the enemy pay ten to one for the damage he succeeded in doing. They were used by the cruiser San Francisco on a night in November, 1942, when a small United States force sank 27 enemy ships, almost completely destroying a large Japanese convoy bound for Guadalcanal when our hold there was precarious. The Mark 3 controlled the fire of the big guns of the battleship South Dakota in the Solomons on the dark night of November 4, 1942, when she sank a major Japanese war vessel eight miles away with two salvos.

Even in engagements in broad daylight, when optics could be used for target angles, these radars still played a vital part in furnishing accurate range which made 5-inch gunfire against aircraft, for example, deadly at long range. Thus, on October 16, 1942, when the South Dakota was attacked by planes, she shot down an even 38 out of 38 attacking.

The Radiation Laboratory, the British Science Mission, and Bell Laboratories

THERE WERE two events in the second half of 1940 which were to be of greatest importance to the Allies' development of radar. They also had a significant bearing on the part which Bell Laboratories was to play in this program.

In July, the newly formed National Defense Research Committee appointed a committee of four, under leadership of Dr. Alfred L. Loomis, to plan and to initiate its programs in centimeter-wave radar. Dr. Ralph Bown, Bell Laboratories' Radio Research Director, was one of the four. This committee, later to become Division 14 of the NDRC, was expanded, and the writer became a member.

While the work of Bell Laboratories was sponsored almost wholly by the Army and Navy and that of the Radiation Laboratory by NDRC, it was most important that the programs of these two large units be correlated to prevent duplication and to insure complete coverage of the technology. The two Bell Laboratories men who were committee members were an aid in the correlation of programs. The Army and Navy technical services, for which Bell Laboratories worked, and the Director of the Radiation Laboratory and his aides coöperated most heartily with the Bell Laboratories in the program planning necessary to make most effective use of both organizations.

In September a British technical mission, headed by Sir Henry Tizard, arrived in this country bringing the full story of the development and use of radar equipments in England. They revealed that in the preceding few months electronic research in England had made available pioneering models of a most remarkable new magnetron—a high-power microwave generator tuned by means of resonant cavities. This magnetron was capable of generating pulses of 10-kilowatt peak power at a frequency of 3000 megacycles (i.e., 10-centimeter wave length). This was more than 50 times as powerful as any other 10-centimeter-wave power source. Radar of military value at 10 centimeters was not possible with the small amount of power available from previous generators.

The availability of this source of high power removed the barrier, which had seemed insurmountable, to the rapid extension of radar into the centimeter-wave-length area. The British mission brought one of the early models—the E1189–12—with them. Some members of the mission and the Bell Laboratories radar research team made operational tests on this model at the Whippany laboratory on Sunday, October 7. These tests verified its reported capabilities.

The advance in magnetron technology which the British researches had brought to light was not only of great importance in the extension of radar to 10-centimeter and even shorter wave-length radio waves but it was also of immediate importance in the 40-centimeter radar developments at Bell Laboratories.

Inadequate output power of the radar transmitter was the chief limitation in obtaining reliably the required ranges against ship and plane targets with the Laboratories' CXAS radar development model. The vacuum tubes of the transmitter supplied 2 kilowatts of pulse power at 40 centimeters. This was insufficient to provide, under all service conditions, the required ranges against enemy targets. The tubes were a recent development of Bell Laboratories, and were the highest-powered 40-centimeter vacuum tube which had been developed. Their output power fell off rapidly at shorter wave lengths. Radar at 40 centimeters with these tubes would have limited application, and their radar use at still shorter wave lengths was not possible. A new source of centimeter wave power was urgently needed. The British mission brought—in pioneering form—the solution.

Immediately after the October 7 E–12 magnetron tests, electronics scientists at Bell Laboratories initiated work on a 40-centimeter resonant-cavity magnetron as well as on types for 10-centimeter and still shorter wave lengths. On December 28, 1940, tests were made on the first successful 40-centimeter model. The availability of peak pulse power of at least 100 kilowatts was indicated by these tests.

If the introduction of higher power into the Mark 3 and Mark 4 radars was to be accomplished with minimum delay, the power had to be limited to 50 kilowatts—25 times that available from the recently developed vacuum tube generators. Fifty kilowatts were adequate to insure that these equipments would have ranges well in excess of the firing range of the

guns they were to control. So a magnetron for this power output was developed and designed at Bell Laboratories and put into quantity production by Western Electric in time to meet the first deliveries of the Mark 3 in October 1941. Development, design, and manufacture within a year after the historic tests on the British 10-centimeter E–12!

The extension of knowledge about resonant-cavity magnetrons was perhaps the most urgent item in the rapid build-up in this country of a centimeter-wave radar research program. The Whippany tests on the British E–12 were made about a month before the Radiation Laboratory began its operation. The formation of an effective research team in electronics by the Radiation Laboratory and the equipping of the necessary highly functional electronics laboratory, even under the urgency of the preparedness program, would require many months.

Bell Laboratories carried the load of centimeter magnetron research, development, and construction of models for radar systems researches, as

pm French Bros - 4/3/46

THREE of the many magnetrons developed by the Laboratories from the basic British design

well as a major portion of that of other essential electronic devices, during the build-up interval of the electronics program at Radiation Laboratory. After the Radiation Laboratory's electronics program was under way, and throughout the war period, Bell Laboratories shared the research and development programs of the magnetron and other centimeter-wave electronic devices with them, with British science and industrial laboratories and, during the later war years, with a few other laboratories of the electronics industry.

TIME was of the greatest importance in the fall of 1940. A man-month of centimeter radar research at that time was to be more valuable than many times that effort even one year later. Beginning with the tests on the British E–12 magnetron, Bell Laboratories' radar research and development program in all of its phases was expanded at an unparalleled rate. Although the attack on Pearl Harbor was as yet a year off, so great was the urge for speed that regular schedules were ignored and there was even then established what later came to be the wartime rate of activity.

During these busy and exciting days of the late months of 1940 and early months of 1941, a spirit of comradeship and coöperation was built up between the radar scientists and engineers of Bell Laboratories, of the Radiation Laboratory, and of the British Commonwealth of Nations which was to be of great value to the Allies' radar program. Bell Laboratories' Whippany radar laboratory, Atlantic Highlands test station, Holmdel radio research laboratory, and electronics laboratory in New York were the scenes of almost continuous conferences. Groups visited Bell Laboratories to see the operation of new centimeter-radar components of great variety and to witness radar systems tests at Whippany and the Highlands.

In the little bungalow at the Highlands, work went forward night and day—with Navy officers ever present—to incorporate into the Mark 3s and Mark 4s the 50-kilowatt power and as many as possible, without delaying production, of the functional improvements which were being made almost daily by the research and development staffs. These visitors crowded and overtaxed its limited area, but they were always welcome. In later days Bell Laboratories people returned the compliment by going to their laboratories to confer and to see the many advances that were coming from their programs. The frequency and number of these visits grew throughout the war. Any day of 1944 or 1945 might have seen from five to 20 Bell Laboratories men at the Radiation Laboratory and a corresponding number from there at Bell Laboratories.

WE LOOK BACK with pleasant memories to the many visits of scientists and engineers from England, Canada, and Australia. Some of the more frequent visitors of note were the late Sir Ralph Fowler, a distinguished scientist of England; Sir Charles Darwin, Director of the British National Physical Laboratory; and Professor J. D. Cockcroft of the Cavendish Laboratory at Cambridge. We had a pleasant and most profitable visit

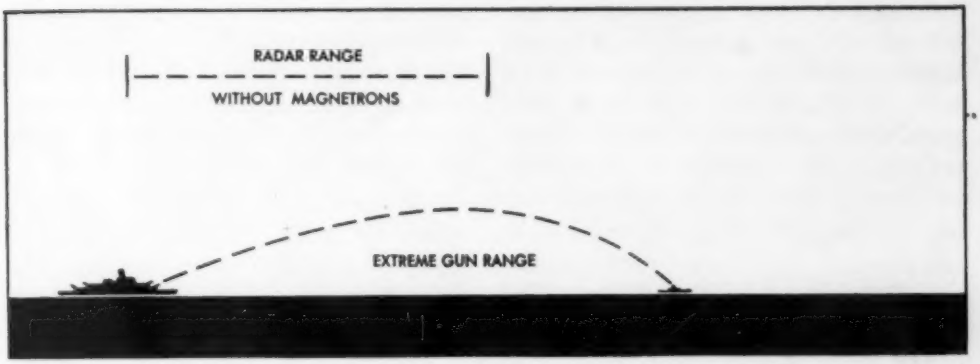
in mid-1941 from Professor M. L. Oliphant of Birmingham University. He was a leader in British radar electronics research and had played an important part in their development of the resonant-cavity magnetron. Upon his departure for England, he said in a letter to the writer:

"During my last days in America I wish to record my deep appreciation for the complete help which I received from you during my visit to your Laboratories.

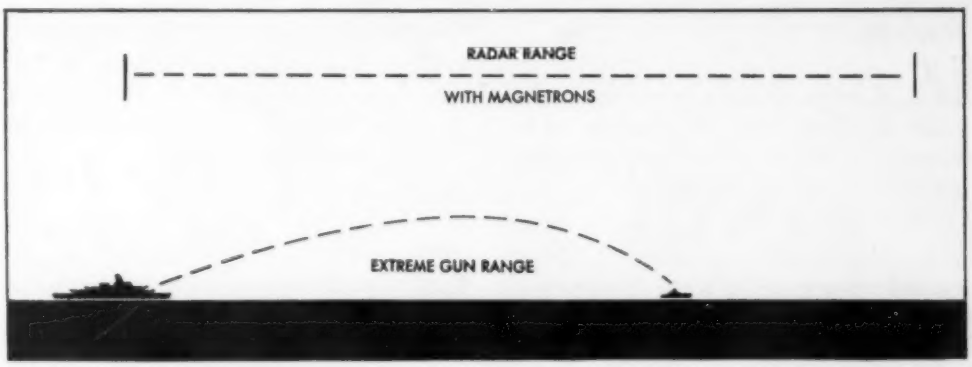
"I am certain that nowhere else in the world is such excellent work going on or such a deeply scientific attack on our mutual problems being waged."

The Development of Radar Systems at Bell Laboratories

THE pioneering radar research of our Army and Navy laboratories in the one- and two-meter wave-length range, that of Bell Laboratories at 40 centimeters, the British contribution of the resonant-cavity magnetron, and the established communications and electronic technology supplied a broad base for our country's huge centimeter-wave radar research and development program of 1941–1945. Dr. Vannevar Bush, Director of the Office of Scientific Research and Development, in commenting on it said that advances were made in five



GREATLY increased power, gained by the use of the magnetron, extended radar coverage well beyond the range of the guns



years which in normal times might well have required three times as long.

The radio spectrum from about 40 centimeters to about one centimeter, 700 to 30,000 megacycles, was explored. Electronic and circuit components essential to the different areas of this wide wave-length band were developed, designed, and placed in manufacture from researches carried out almost concurrently. A very large number of radar systems operating in this wave-length band, progressing steadily toward shorter wave lengths as the war advanced, and dependent for their successful functioning on the new electronic and circuit components, were developed and designed for production and use. The dollar volume of production of these radar systems and components was in excess of $2,000,000,000. These facilities were of greatest importance to our victories in every sector of warfare.

BELL LABORATORIES became the largest developer of centimeter radar systems and their associated electronic and circuit components. More than 90 such radar systems were in development in these Laboratories. Some 60 different systems were produced by Western Electric before V–J Day and almost all of them were in active service, many in tremendous quantity.

These systems were of great variety, extending across the whole area of radar use and covering the full range of the wave-length band. Each was suited to a specific application of either land, sea, or air warfare. Our Army ground and air forces, our Navy's ships, submarines and planes, and our Marines' landing forces were all equipped with radars of Bell Laboratories development. Some of them were adopted by our Allies, and the Western Electric manufactured them in large quantity for their use.

Fire-Control Radar for the Fleet

THE CXAS radar which led to the large-quantity production of Mark 3s and 4s pioneered the fire-control radar developments for our Navy and Army. Throughout the war Bell Laboratories developed substantially all that our Navy used. This was one of the two largest sectors of its radar program. More than 20 systems, suited to guns of different calibers and to a wide variety of applications, were developed at the Whippany laboratory.

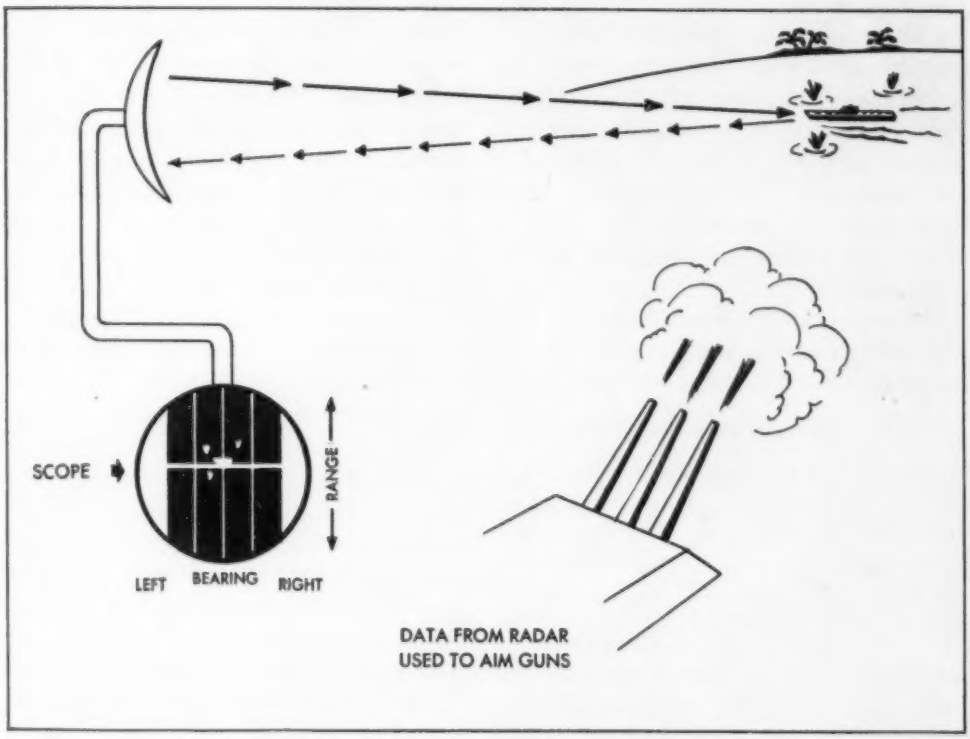
With a large share of the responsibility for the Navy's research and development program in radar fire control from the time of the pioneering CXAS development, Bell Laboratories' knowledge of the Navy's gun-direction problem and radar's part in it steadily grew. There developed a continuously more effective working relationship between the technical officers of the Bureau of Ordnance and the Laboratories' staff. Regularly scheduled monthly program review conferences were held at Whippany, attended by that staff, by Bureau of Ordnance officers and, frequently, by Western Electric's manufacturing engineers. There were almost daily individual contacts in Washington, at Whippany, at some Navy Yard, on a ship, or at the Hawthorne Works of the Western.

This continuing intimate relationship between user and developer made possible a very rapid advance in one

of the most technically difficult sectors of radar. At the war's end every type of Navy gun had a directing radar suited to its special needs. This direction was, in general, more accurate and versatile than that afforded by optics which had been under development for decades. Advances were so rapid and intensity of effort so great that for some types of guns, such as those of the main batteries of warships and cruisers, three succeeding radars were developed, designed, manufactured, and placed in active service.

The Mark 3 was available for main-battery use at the time of the Pearl Harbor attack, the Mark 8 followed in early 1943, and it in turn was followed by the Mark 13. Each operated at a shorter wave length than the one it succeeded, and had a higher degree of accuracy, improved operational features, and added functional abilities. All of this within a five-year interval!

A radar was not made obsolete by its more modern successor, for a continuously increasing part of Bell Laboratories' expanding development effort was directed at the incorporation of the new art into the older radars. The modernization apparatus elements were sent to the fleet as "kits" and installed, according to procedures carefully worked out by the



How RADAR helps control the fire of a ship's guns: the 'scope picture accurately presents the range and bearing of the target (large spot) and of shell splashes (three small spots)

Laboratories, into equipments in service by Western Electric's field engineers and Navy personnel. There were in the fleet on V–J Day large numbers of modernized Mark 3s and 4s, and the Mark 8, which had undergone many modernizations, was still a most valuable element in radar direction of large guns.

Radar for the Submarine

JAPAN'S conquests during the first eight months of the war extended her island empire to the south and east across vast expanses of ocean. Her far-flung fronts were some 3,000 miles from Tokyo. The flow of men and materials from the homeland to the fronts had to be almost entirely by ship. This presented a most favorable situation for our use of the submarine—the Navy's most effective agent for the continuous harassing of shipping lanes and destroying of tonnage. This opportunity was recognized at an early date and a large submarine construction program was initiated.

Before radar, the submarine, of necessity, did the greater part of its hunting by day, when enemy ships could be detected by sight at much greater distances than at night by underwater acoustic detection equipment. The airplane, because of its ability to patrol vast areas, greatly increased the hazards of the submarine; and if the enemy had a sufficient number of them, he could largely reduce the effectiveness of our submarines. Our Navy's research laboratory developed an airplane detection radar operating in the meter-wave-length range for our submarines. Its value was restricted to early warning of enemy planes flying at not too low altitudes, and it was of little value as a locator of enemy ships or for detection of low flying planes.

This was the situation in early 1941 when officers of the Navy's Bureau of Ships brought to Bell Laboratories the radar problem of the submarine. Radar for detection of low flying planes, for location of enemy ships, and for torpedo direction was urgently needed. If radar could be developed to meet these operational needs and to accommodate itself to the limitations of space and to the low antenna height that would be practicable, the submarine could then hunt by night as well as by day, with greater safety and with much greater attacking power.

Studies at Bell Laboratories indicated that a centimeter-wave-length radar, suited to the submarine's needs and limitations, should meet the situation. Work was undertaken in May, 1941, and from that time until the war's end these Laboratories carried the submarine radar development responsibility for our Navy.

Western Electric produced the first centimeter-wave radar for submarines in April of 1942, and production con-

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RADAR proved itself to be the vitally important attacking aid of the submarine which had been hoped for. All submarines were radar equipped: they searched out the enemy with radar, they kept themselves alerted to the dangers of enemy attack by radar, and at night they made their deadly attacks with radar-directed torpedoes. No other area of the Bell Laboratories' radar program has made so great a contribution per man hour of effort as has that for the submarine. We take special pride in it.

tinued to the war's end. The pattern of advancing technology for submarine radar parallels that of ship fire control. New and shorter wavelength radars supplanted the old, with the modernization of earlier equipments proceeding continuously.

Fleet Admiral E. J. King after the war's end reported: "Of all enemy merchant shipping sunk in the Pacific, submarines accounted for approximately 8,300,000 tons, or two-thirds. Of the naval vessels that Japan lost in the war, submarines sank one-third."

Radar for the Airplane

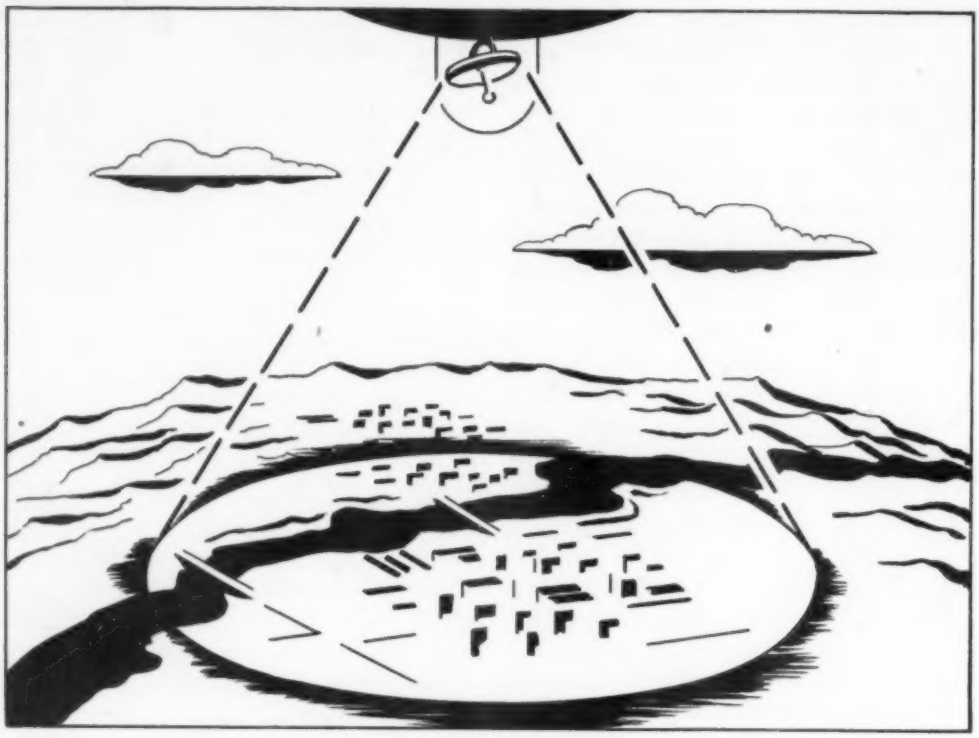
THE Radiation Laboratory and Bell Laboratories shared, in a spirit of cooperation and with continuous interchange of ideas and information, almost the entire load of research and early development in our country's airplane radar programs. The great variety of planes of our Army and Navy made necessary the development of many different functional types of radar. The tremendous number of planes led to a correspondingly large number of airborne radars. This was the largest of all sectors of radar, from research through production to military use.

Our Army and Navy planes used radar for navigation; for reconnaissance in searching out the enemy and following his movements; for interception of his planes and directing our planes' movements in their attack; for fire control of the guns of our planes; and for bombing of his ships, submarines, troops, airfields, tactical positions back of his lines, and his manufacturing plants and transportation facilities.

THE AIRPLANE has more profoundly affected military strategy than any other one weapon which has been introduced into modern warfare. It was first used in World War I, but had little effect on strategy or on victory. In World War II it played a major part in warfare on land and sea. Our might in the air determined the length of the war. Radar was one of the factors that made it possible for the airplane to play its commanding role. Without it, the airplane's value in the war would have been very much less.

Bell Laboratories developed radars for each of these functions. Similar to the pattern of progress described under "Fire Control Radar for the Fleet", improved models for each function followed one after another. With the great variety of functions, this led to a volume of effort at Bell Laboratories equal to its combined effort for ship, submarine, and ground radars.

Weight and space are at a high premium in all airplanes—more in some than in others. Even the giant B-29 could not accept an equipment for any function, no matter how important it was, until its weight and size had been "shaken down" to the lowest level possible. All airplane radar developments, therefore, had in common a highly important requirement of minimum weight and size which did not exist in radar developments for other scenes of service. The interests of minimum weight and volume are better served the shorter the wave length employed. For this reason, as well as for some that are more technical, Bell Laboratories' first airplane radars operated in the 10-centimeter wave band, and later



A RADAR ANTENNA, installed in a turret under the fuselage of a B-29 bomber, "scans" the target area

models operated at wave lengths a small fraction of this.

The Laboratories' first airplane radar development was done in co-operation with the Radiation Laboratory. It was for the night fighter plane in its interception and attack of enemy bombers. The Radiation Laboratory carried the project to the research model stage, and under Army contract Bell Laboratories carried the development forward to a production design. The latter work began in March, 1941, and Western Electric produced the first equipments in the second quarter of 1942.

These equipments were not used for their intended purpose, but were modified for ship and plane use to combat the submarine menace along the Atlantic during 1942. During the early months of the submarine warfare they were the only equipments available for some aspects of our anti-submarine action.

The Laboratories' second step in interceptor development was the SCR–720. It became available in 1943 and was standard for our Air Corps and the British RAF throughout the remainder of the war. Several thousand were produced, and were used on all fronts in Europe and in the war against Japan. Many hundreds of enemy planes and buzz bombs were destroyed by planes

equipped with the 720. Perhaps of even greater importance was their protection of large tactically important areas from night-time bombing. Attack by planes employing this radar was so deadly that, after experiencing it, the enemy discontinued sending bombers over areas so protected.

The SCR–517, followed by the SCR–717, in its several modernizations, were the navigation and search airplane radars of our Army Air Corps. Bell Laboratories developed the 517 in 1941 and the 717 in 1942–1943. The 717s were made in large quantities by Western and by the Philco Company.

IN MANY respects the Laboratories' most difficult radar development for air was an all-purpose radar for the carrier-based plane. It owed much of its difficulty to rigorous requirements of weight and trouble-free operation.

The performance afforded by centimeter-wave radars was much needed by our carrier planes in 1942. They were using a radar employing a wave length of somewhat less than a meter. The radar was light enough in weight but did not have the performance capabilities of the centimeter-wave radars. The centimeter-wave radars for land-based planes were too heavy —weighing more than 350 pounds— and occupied too much space for use by the carrier plane.

In May of 1942 Bell Laboratories undertook the development of a radar combining navigation, search, and interception functions, suitably packaged and of adequately limited volume for carrier plane installation. It was to weigh about half as much as radars employed in land-based planes, to perform about as well as those weighing twice as much, and to meet most rigorous requirements covering maintenance-free operation.

The development met most of those objectives by mid-1943, and production was started by Western Electric before the end of that year. During 1944 and 1945 Western and the Westinghouse Company produced many thousands of this equipment. It was produced probably in larger quantity than any other centimeter-wave radar equipment of the war.

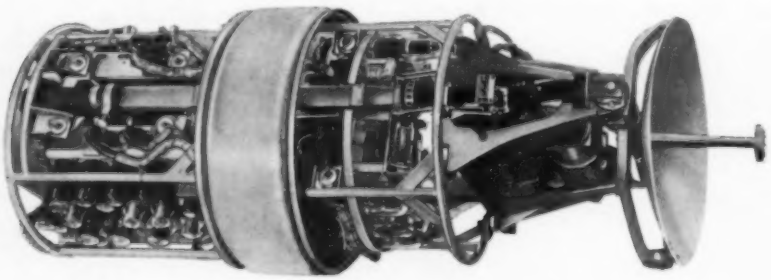
In reporting on the equipment one of our Navy's carrier plane pilots said: "This radar works well with the many jobs we are called on to do. These include searching out Japanese targets, intercepting his planes, navigating in strange territory, and homing to our carrier. It is also most helpful to the pilot in his flying in, over, and around tropical rain squalls and pointing out targets through overcast."

RADAR bombing equipment evolved from the search radars. As shorter wave lengths—still shorter than 10 centimeters—became available, sufficient resolution of objects was possible to permit the recognition and bombing of many sorts of specific targets, such as harbor and riverside installations, bridges, and even certain industrial plants. Bell Laboratories researches in radar bombing, which began in 1941 under authorization by the Army Air Corps, were gradually expanded, and led to the development and design of several radar bombing equipments suited to different applications.

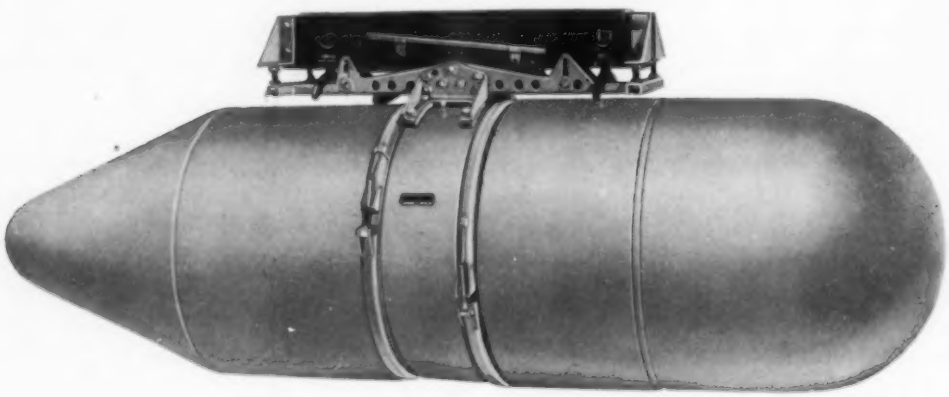
From these designs Western Electric produced the largest volume of

radars for bombing of any supplier. One of these equipments became the standard radar bombsight of the Army and Navy for bombing ships at sea from relatively low altitudes. Reports from the Pacific Theater indicated that a bomber squadron's efficiency in ship sinking increased several

researches had as their ultimate objective the bombing from high altitude through the overcast with an accuracy against individual targets equal to that of optically directed bombing. This was accomplished during the final months of the B-29s over Japan. Radar bombing scores



COMPACTLY BUILT into a bomb-shaped casing, this carrier-plane set reached the highest production figure of any centimeter-wave radar



fold after the introduction of this equipment.

Two of the equipments were standard for B-29s in their bombings of the Japanese home islands. Most of the damage done by the B-29 raids was by bombs directed by these radar equipments.

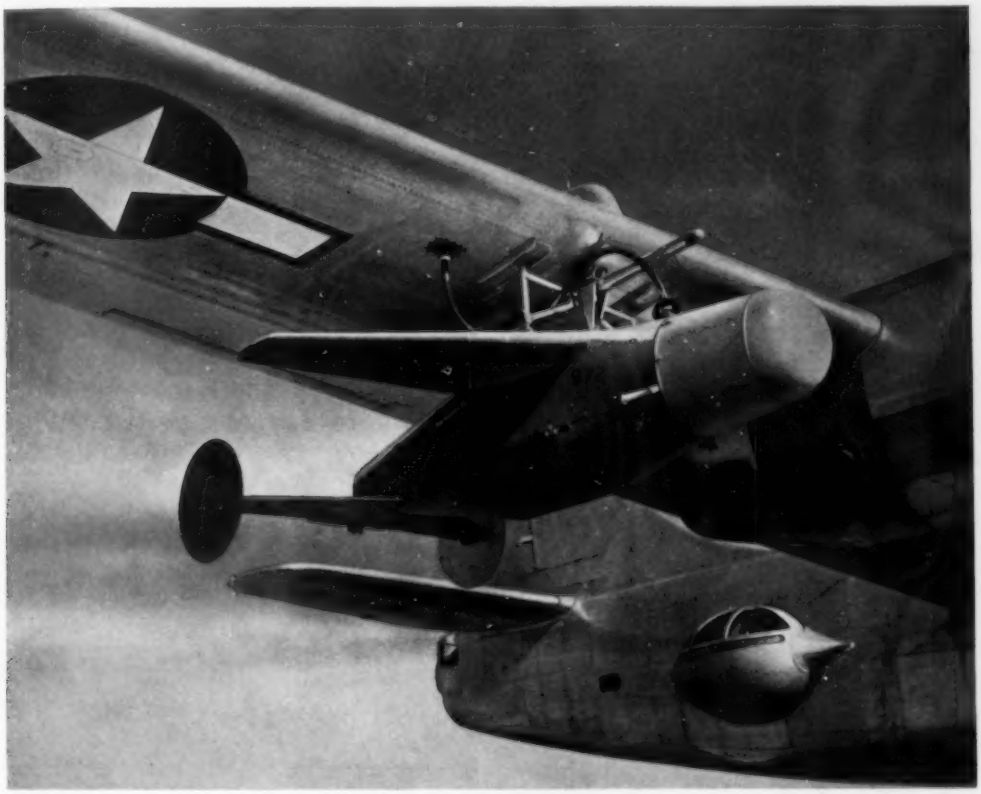
The Laboratories' radar bombing

against individual targets were equal to those of optical bombing under good visibility. From some viewpoints this was a greater technical accomplishment than that of our accurate fire control radars. The radar bombing equipment not only had the same objectives of high precision as did the fire-control radars; it also had

to meet the severe weight and size limitations essential for airplane use —a most difficult task which required almost four years of intensive research and development on the system and its component apparatus.

The Radiation Laboratory and Bell Laboratories continuously interchanged information and ideas on radar bombing. There was also a sharing of responsibility and work load on some of the projects.

Bell Laboratories coöperated with the NDRC in the development for the Navy of a radar-guided winged bomb, called the Bat. Under a Navy Bureau of Ordnance contract the Laboratories developed the radar head which supplied the directional or "homing to the target" information. The NDRC developed the glider and automatic controls for its steering from radar-received data. It was standardized for use and large quantities were manufactured. The Western Electric Company produced the radar heads according to Laboratories' designs. The Bat sank many tons of Japanese naval and merchant shipping during the final months of



THE "BAT", a radar-guided winged bomb, slung under the wing of a Navy bomber

the war. It was the first missile of its type ever successfully used in combat.

Radar for Ground Use

RADARS operated from the ground have found broad application by the Army Ground Forces, the Marines, and the Army Air Forces in the protection of airfields and other fixed installations from enemy airplane attack. They have also had extensive use in the protection of newly won beachheads and permanent shore installations from attack by ships and planes. Ground radars have been of two general classes: search and fire control.

During the 1930s the Signal Corps carried out a pioneering program on radar at their Fort Monmouth, N. J., laboratories under the direction of Colonel (now Maj. Gen., retired) Roger B. Colton, and completed the development of two ground radars before the war began. Like the Naval Research Laboratory, their program was in the meter wave-length range. They directed their attention to the development of equipments for search and early warning of enemy planes.

Bell Laboratories was brought into contact with the Fort Monmouth developments in 1938, and from that time there was a continuing interchange of information between the two groups. In mid-1939, when the Laboratories moved its first centimeter-wave-radar equipment from the Whippany laboratory to the Atlantic Highlands laboratory, Colonel Colton and his aides were among the first visitors there, and they continued to follow the developments at the Highlands laboratory.

In the spring of 1940, the Signal Corps requested the Western Electric Company and Bell Laboratories to undertake the design-for-production and the manufacture of one of the search and early-warning radars which the Fort Monmouth laboratories had developed. The Signal Corps wanted this equipment in quantity production at the earliest possible time.

In order to proceed with the design and preparation of manufacturing information at the greatest possible speed, the Bell Laboratories' project group was provided with work space at Fort Hancock, N. J., in close association with the Signal Corps group which was developing this radar. As rapidly as design information was completed on an element of equipment, Western Electric proceeded with its manufacture. The first equipment, coded SCR–268, was delivered by the Western Electric in February, 1941, less than eight months from the beginning of Bell Laboratories' work on the project.

WESTERN ELECTRIC continued the manufacture of this equipment until 1944. More than 1,000 equipments were produced, and they saw service in almost all theaters of the war. Bell Laboratories made two major modernization redesigns of the equipment and there was a continuous flow of detailed changes that required the engineering of modernization kits for application to equipments already in service.

The SCR–268 equipment was mounted in a truck and trailer. Other early warning equipments developed by the Signal Corps laboratories were still larger and had to be permanently

installed where they were to be used. Combat experience soon pointed out the need for a search equipment which was sufficiently light in weight and packaged into small enough units so that it could be flown into newly established airfields. In order that protection from enemy air attack on these fields could be quickly established, the equipment had to be capable of being installed and operated within minutes after it was flown in. The requirement for light weight and unit packaging could only be met by employing a much shorter wave length than that of the SCR–268. Technical requirements also indicated the use of a shorter wave length.

TO MEET these requirements, Bell Laboratories developed for our Army Air Forces and Marines an air-transportable centimeter-wave radar for search and early warning of enemy planes. This equipment was coded the AN/TPS, and it was manufactured in large quantities by Western Electric. It was extensively used, and was of special importance in defending the many conquered Pacific Islands from enemy raiders. Several were used on Iwo Jima and Okinawa.

Bell Laboratories developed three fire-control radar equipments for ground use: two for use by the Army Ground Forces and one for use by the Marines.

The SCR–296 fire-control radar was developed for the protection of shore installations from attack by ships. It was permanently installed, with its antenna mounted on top of a tower of height varying up to 100 feet, depending upon the topography of the location. The antenna had to be sufficiently high so that its radar beam could reach enemy ships several tens of miles beyond the shore, in order that shore defenses could be alerted in time and "tracking" for fire control be under way well beyond the range of the guns controlled. This radar employed the wave length and many of the techniques of the original Mark 3 for ship fire-control use. A few hundred of them were manufactured by Western Electric, and were installed for protection of shore installations in many of the theaters of war. In common with other radars, there was continuous modernization of the equipment to keep its performance abreast of the advancing art.

An anti-aircraft radar fire-control system, truck and trailer mounted, which incorporated a search radio beam as well as one for gun-pointing, was developed for control of the fire of the anti-aircraft batteries of the ground forces. It was coded SCR–545. The search beam was in the one- to two-meter wave length range and provided a beam of such breadth that it was easy to locate planes at a distance of many miles. As they approached gun-fire range, a particular plane was selected for "tracking" and the centimeter-wave "gun-pointing" beam followed this plane and continuously supplied information for direction of the gun fire. This equipment was used in the protection of the Anzio Beachhead in Italy and in the Pacific Theater.

A considerably lighter truck-mounted fire-control radar, the Mark 16, was developed for the Marines. This equipment was suited to their needs in the Pacific Islands warfare. It was taken ashore soon after a beachhead was established, to protect it from attack by planes or ships. A

few hundred of them were used throughout the Pacific Theater in the protection of newly won islands.

Components and Circuit Elements for Radar

IN THE DEVELOPMENT of new communications systems there needs to be the most intimate interplay between the advancing technology of the system, its components, and its circuit elements. By experience gained in the development for the Bell System of new radio and wire transmission systems with their intimately related switching systems, Bell Laboratories has evolved a most effective pattern of relationships and team play between new systems philosophers, developers, and engineers and the scientists who carry out researches basic to the new components and circuit elements. The knowledge of how to integrate into an efficiently working team men having the great variety of technical skills essential to the simultaneous creation of new systems and their new components and circuit elements was necessary for the Laboratories' development of almost one hundred new centimeter-wave radar systems within a period of some five years.

RADAR, *like all communication systems, is an ordered aggregate of electronic and electro-mechanical components and circuit elements interconnected by suitable electrical conductors. Each component and circuit element is designed to meet its functional part of the system's operation. The interconnection is engineered so that the integration of the operations of the individual elements produces the desired system performance.*

Beginning with Bell Laboratories' first radar studies in 1938, those expert in the research and development that lead to new components and circuit elements were made a part of the radar systems research and development team. New electronic devices, electrical networks, transformers, coils, potentiometers, resistances, relays, condensers, thermistors, crystal converters, and varistors were made available first as research models for systems study and later as development models preliminary to the final design for service. In each succeeding year the number of new components standardized for production was greater than in the previous year. In 1944 the design of more than 1,500 components essential to radar was completed, in comparison with less than 1,000 in 1943.

NOT ONLY were the radar systems of Bell Laboratories development dependent upon these new components but also those developed by others would not have been possible without them. The demand for them was so great that even with its large expansion Western Electric could not produce all that were required. The Laboratories' new components were always placed in manufacture by Western, but many were later shifted in whole or in part to other manufacturers in order that Western might make available capacity for still newer components which had to be produced with greatest speed in order to meet new radar systems needs.

New electronic devices—magnetrons, beating oscillators, pulse power tubes, intermediate frequency amplifier tubes, gas switching tubes and many other electronic elements—

were the keystones to the rapid progress of the centimeter radar art. Bell Laboratories was a major contributor of new electronic devices of almost all varieties which determined the speed of radar's advance. During the 1940–1945 period, the Laboratories designed and standardized some 175 different electronic devices essential to radar. Western supplied them in large quantity. The dollar volume of their deliveries exceeded $100,000,000; almost twice the dollar volume of all electronic devices manufactured for Bell System use from 1915 to 1940.

LARGE QUANTITIES of Bell Laboratories developments were supplied by many other manufacturers. The requirements for some types were so large that it was necessary for the Services to obtain production from several manufacturers. In the case of an intermediate-frequency amplifier tube—the 6AK5—there were five suppliers in addition to Western.

Bell Laboratories electronics developments covered the wave band from 40 centimeters to 1 centimeter and every radar electronic function except display. The cathode-ray tubes used in the video system to display the radar pictures were developed by others. While the Laboratories' electronics programs were carried out under Army and Navy contracts, they were closely integrated with those of the NDRC. In authorizing a program in one of the new wave length sectors, the Bureau of Ships wrote in part: "The Bureau expects the Western and Bell Laboratories to assume the same responsibilities in the development and manufacture of the electronic devices for the new —— band as have been carried so well in the other bands."

THE 6AK5, one of the most important vacuum tubes developed for radar use

Bell Laboratories' contribution to the development of the many other types of components, circuit elements, and coaxial cable and wave guide transmission interconnectors was as broad in scope and as fundamental to all centimeter-wave radars as were its electronic developments.

Radar Systems—Designed for Service

THE radar systems operating in the wave band from 40 centimeters to 1 centimeter made the first general use of this vast range of the radio spectrum. For several years before 1940, research in Bell Laboratories was probing this wave band to de-

termine its value to communication. The volume of this research was in balance with the many other sectors of the research program.

With the advent of radar and war, Bell Laboratories expanded this research effort several fold, and the scientists at the Radiation Laboratory also made large contributions in this area. Building upon the knowledge so rapidly accumulating from this greatly expanded research effort, the Bell staff of systems and components developers produced in rapid succession development models of radar systems having greater range of vision and higher resolving power and capable of more accurate measurement of an object's location. In the development of these radars, the Laboratories' research and development teams were operating in familiar territory, for their pattern of effort was the same—except for the pressure of time—as that normally followed in obtaining new knowledge through research and then applying it in a closely integrated program to the development of a new communication system and its components.

Following the development model, though getting under way before its completion, comes design for service. This is an area of communications technology that Bell Laboratories has developed to a high state of proficiency. Its responsibility for the design of the communications facilities for Bell System use, with the philosophy of designing facilities that provide the best communications service at the lowest possible cost, has built a "service for the user" attitude into the fiber of the organization. In order to arrive at the best designs for service, there have evolved at the Laboratories through the years highly effective teams of electrical and mechanical designers and of chemical, materials, and metallurgical engineers closely integrated with scientists, systems engineers, and components development engineers. These teams are equipped with specialized facilities for the evolution of service designs and for appraising their adequacy.

MORE THAN HALF of the Bell Laboratories design organization—with greatly expanded aid in drafting, laboratory experimenting, testing, and model construction—were engaged in designing radar systems and components. During the early years, design for service was the most difficult sector of radar effort. This was due principally to the time schedules imposed by war and to an inadequate knowledge of user or service requirements.

The need for equipments was so urgent that a greatly compressed time scale was a necessity throughout the war, but was at its maximum during the early years. The best possible, within the time, had to be done; and great ingenuity was shown in the overlapping of procedures that normally best follow one after another. Not only were procedures within the Laboratories telescoped, but also the final design effort and Western's engineering and planning for manufacture were carried on practically simultaneously. Had it not been for the many years of coöperative effort of these groups under normal conditions, time compression so effective would not have been possible.

A step that proved of great value in time saving was the placement of

large groups of Bell Laboratories designers and their draftsmen at each of Western's manufacturing centers. Their work was so highly secret that the large areas of space they occupied were enclosed in wire screen. These became known as the "Labs' Cages," and they were the focal points where Army and Navy officers and Laboratories and Western engineers settled a steady stream of detailed questions on materials, processing, design, and testing. The "Cages" were kept in hourly contact with the development teams at the Laboratories through telephone and teletypewriter. Almost every day saw engineers from the "Cages" at the Laboratories and those from the Laboratories at the "Cages".

IT SOON became evident that knowledge of user requirements was inadequate. Radar was a new military instrument; it had never before been used in warfare. It was to be used by every branch of our Services. The theaters of battle were all over the world. In consequence, environmental problems were world-wide.

The dry and dusty heat of the African desert, the humid heat of the tropical islands of the Pacific, the cold and ice of the Artic, and the low pressures and temperatures of planes flying at 20,000 feet were extremes of climatic conditions in which radar must operate trouble free. The design-for-service of a radar performing similar tasks was quite different depending on whether it was for use in a surface vessel, a submarine, on land, or in a plane. Differences in available space, shock and vibration conditions, details of operating procedures, and many other factors combined to make the radar for each task a special job.

Neither Bell Laboratories engineers nor the technical officers of the different Services knew, at the war's beginning, the answers to many of the questions on design-for-service posed by this variety of climatic environments and of locale of installations. However, the Laboratories had specialists in large number with the knowledge of how to determine requirements for trouble-free, convenient, and effective operation and maintenance and how to apply them in design. These specialists, in closest coöperation with the different Services, proceeded with greatest energy to obtain knowledge so that equipments could be designed to meet any of the service and environment conditions of world-wide war.

They went to the Tropics, to the Arctic, in planes to 20,000 feet altitude, to the sea in ships of many classes, and under its surface in submarines. They observed service and environment conditions of every kind. The knowledge gained through such visits, from laboratory investigations that followed, and from consultations with the different Services, was translated into design requirements. Facilities were developed or procured for making tests in the laboratory under conditions closely equivalent to those in service. At the war's close, the radar test laboratory at Whippany was one of the most completely equipped in the country for testing of ground, sea, or airborne radars.

With steadily increasing knowledge of the users' needs, and with facilities for design and service test under constant improvement, the radars of Bell Laboratories' development each

year gave more nearly trouble-free service and required less maintenance than those of previous years. In the final months of the war, the bombing radars in the B-29s were giving better than 98 percent trouble-free service on their missions over Japan.

Rear Admiral G. F. Hussey, Jr., Chief of the Bureau of Ordnance of the Navy, in a letter of comment upon the design of one of the last ship fire-control radars, wrote in part:

"The Bureau considers that this equipment represents a marked advance in radar design, particularly from the standpoint of reliability and ease of maintenance. It indicates clearly the benefits to be derived from experience, sound design engineering, and excellent manufacturing techniques. While fleet experience with this equipment is still limited, reports indicate that it is considered the best radar equipment yet installed on shipboard."

Special Services Essential to the Radar Systems Programs

IN ASSUMING the responsibility for so large a portion of centimeter radar technology—the underlying research and the development and design of radar systems and components—it was necessary for the Laboratories to carry out several special assignments closely related to its radar systems programs and essential to the Army's and Navy's most efficient use of the systems.

These assignments included the development of radar test sets, the preproduction of radar systems and components, the preparation of technical manuals and instruction books on radar systems, and conducting a radar school for commissioned and enlisted personnel and civilian experts of the Army and Navy.

RADAR TEST-SET DEVELOPMENT

A RADAR SYSTEM is a most complex equipment. Typical radars have from 50 to 250 vacuum tubes, associated with many times that number of condensers, resistances, transformers, coils, electrical networks, and various electro-mechanical components. Notwithstanding most careful design, it is easy for radar performance to become impaired under operating conditions.

The greater the range of coverage and the more accurate the data of a radar, the more valuable its information is likely to be. The range of coverage may fall to a fraction of the normal, or the accuracy of measurement may decrease by a large amount, with nothing in the radar's performance to indicate it. There must be test facilities at the battle fronts which make possible checking and adjusting the radar to insure that the normal range of coverage and highest possible accuracy are always realized.

Previously existing electrical test equipments were not suited to the solution of most of centimeter radars' test problems. Their use of new wave lengths and of a large variety of new circuit techniques made necessary the development of many completely new test sets.

Radar test-set technology had to be kept in step with the rapidly moving radar systems developments. This could only be done by a most intimate association of test-set development with systems development.

The pattern of the test-set work became substantially the same as that for the systems themselves. The Radiation Laboratory and Bell Laboratories shared the major portion of the responsibility. The two organizations worked in close coördination with each other and with the Services to prevent duplication and to insure complete coverage.

From 1940 to 1945 the Laboratories developed and designed for service over 200 different radar test sets. They were of great variety: special oscilloscopes, signal generators and power meters for all the different wave length bands, frequency meters, range calibrators, phantom targets and echo boxes are typical test set names. Western Electric produced more than 75,000 sets of Laboratories' design. The rate of production was 5,000 per month at the war's end. The Army and Navy used test sets in increasing number and with ever-improving effectiveness in maintaining radar systems at the battle fronts at highest level of performance.

Pre-Production of Radar Systems and Components

After the design model of a radar system was approved by the Service using it, an interval of four to eight months might well elapse before quantity production could begin. This interval was used in the procurement of materials, the design and construction of special tools and equipment for production and testing, and the preparation of manufacturing space. This interval was of great concern to the Services; it was not possible for them to begin their training programs or to make limited tactical studies at the front until the quantity production line had started moving. Four to eight months of most valuable time were almost completely lost.

To meet this situation, Bell Laboratories, at the urgent request of the Services, began the construction in special job shops of a limited number —from 5 to 30—of its newly developed radar systems during 1943. This production could be under way as design was nearing completion; and since it was intimately associated with the development teams, the work could be carried out without operator training and with limited special tooling, equipment, and test facilities. It was thus possible for deliveries in these limited numbers to begin almost immediately after the approval of the design model and to be completed before quantity production started.

While this was a very expensive way to produce radar equipments, the service proved to be of such great value in its saving of time that it grew rapidly. It became necessary to limit pre-production by a critical examination of each request, in order that its volume might not overtax the Laboratories' capacity and slow down its development programs.

The 1943 dollar volume of radar systems pre-production was $3,000,000, and in 1944 it increased more than three-fold. It continued at an average level somewhat in excess of $1,000,000 per month until the war's end. This service was unique; its nearest equivalent was a job shop at the Radiation Laboratory for construction of development models in small quantity for similar purposes.

Bell Laboratories also made, on a

To BRIDGE the gap between design and quantity production, the Laboratories set up a pre-production shop—a corner of which is shown here—where limited numbers of new equipments were completed

job shop basis, a large volume of its components of recent development in order that the Service laboratories, the Radiation Laboratory, and industrial laboratories could obtain new components for evaluation and use in the development of radars in advance of the time Western could start quantity production. This service was of great value in accelerating evaluation and standardization of new components by the Services and the development of radar systems by others.

TECHNICAL MANUALS AND INSTRUCTION BOOKS

RADARS were sent to far distant war fronts in Europe and Asia. It was most important that the officers and men of the Services at the fronts be provided with complete technical manuals and instruction books for each radar system. As these systems were modernized, new editions of the books and manuals describing the changes had to be at the fronts as soon as the "modernization kits." Communications systems, sonars, gun directors, and many other instruments of war which Bell Laboratories developed had a similar problem of technical manuals and instruction books.

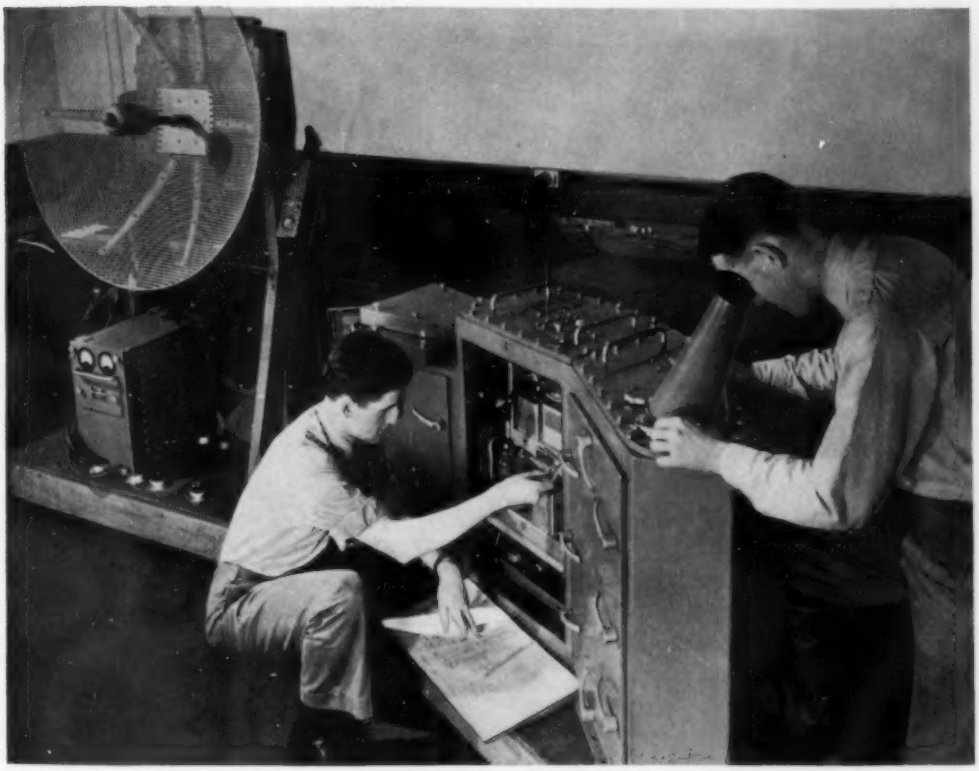
To care for the rapidly expanding load of book writing, the Laboratories established an editorial department which worked in intimate relationship with the development groups responsible for each of the different military equipments or systems. In 1944 alone, 366 separate instruction books and technical manuals were pre-

pared for the Laboratories' developments of that year. More than 200 of them were concerned with radar systems. There were nearly 60,000 pages of text for all books and manuals, and more than 17,000 illustrations. In that year the Laboratories became the country's largest publisher of new books.

School for War Training

In a manner similar to its preparation of manuals and books, the Laboratories segregated all of its instruction activities for the Services in a "School for War Training." The staff of the school was selected principally from members of the Laboratories' technical staff and engineers lent to the Laboratories by Associated Companies of the Bell System, and during the maximum enrollment numbered about 75. The school occupied a number of lecture, laboratory, and conference rooms. The courses covered lectures, laboratory work, conference quizzes, and examinations. Many were at the college level, and students were required to have had previous training in science and mathematics.

During its more than three years of operation, the school conducted about 125 different courses, which were at-



Future Navy radar officers learn about fire control radar at the Laboratories' School for War Training

tended by some 4,200 students assigned to them by the Armed Forces. More than 80 percent of this number were from the Army and the rest from the Navy. More than one-half of the School's courses were concerned with radar. The policy of the Services varied as to the number of their personnel who were given this basic training. All of the Navy officers who were in training for fire-control assignment attended the school, and the Navy required one graduate aboard each major combat vessel. Almost every new radar system brought a group for special training in its theory and practice.

Coöperation with Others

THE ALLIED NATIONS matched the Axis Powers in the application of science to warfare before the mid-point of the war had been reached, and surpassed them by its close. As the Axis had devoted a large and increasing portion of its science and technological strength to the development of new instrumentalities for war during the preceding decade, and the Allies' similar effort had been extremely small in comparison, this was indeed a remarkable accomplishment.

Many factors contributed. Two of the most important were: The Allies' scientific and technological strength was greater than that of their enemies; and the coördination of effort and the coöperation of scientists, technologists, and the military within each allied country and between them were at a high level of effectiveness while, as we learned after the war's end, the corresponding coördination and coöperation of the Axis Powers were at a low level.

Radar development was a model of effective coördination and coöperation within each allied country and between them. Bell Laboratories was one of the foci of coöperative effort. It is with pride and satisfaction that we look back on our participation in the coöperative activities from mid-1940 to the war's end. Information from Bell Laboratories radar programs was available to all who were cleared by the Army or Navy. The laboratory door was always open for the entrance of authorized visitors, and through it the Laboratories' technical memoranda went to all groups who had official clearance.

In 1944 there were approximately 20,000 authorized visitors to Bell Laboratories. Some 60 percent were interested in radar technology. Nine thousand were from American industries, 8,500 from our Services, 1,700 from the NDRC, and 500 from our Allies.

While no accurate count has been kept of radar memoranda sent to the NDRC, the Services, and American industry, a count of those supplied the OSRD for transmission to our Allies has been kept. From mid-1942 until the end of 1944, about 500 such reports were sent. This is approximately one-third of the total concerned with centimeter-wave radar which OSRD transmitted. One-third was supplied by the Radiation Laboratory, and one-third by all others. Prior to mid-1942, Bell Laboratories, after Service clearance, supplied the British Scientific Office in Washington with some 300 memoranda for transmission to the British Commonwealth organizations.

In like manner, Bell Laboratories obtained information of aid to its

program from the laboratories of our Allies, Government, and American industry. Because of its volume, mention has frequently been made of the coöperation between these Laboratories and the Radiation Laboratory.

Bell System's Contribution to Victory

IN A companion article, the story of Western Electric's enormous production of radar for our Army and Navy is told. Western's and Bell Laboratories' contributions are an integrated whole, one complementing the other. There was no more of a discontinuity in the smooth and ordered flow of the radar program from research to completed equipment between Laboratories and Western than between parts of the program within each organization.

This teamwork is an old story; for the two organizations have, over a long period, provided new communication facilities for the Bell System through a technical program beginning with research at the forefront of science and proceeding through ordered steps of development, design, manufacture, and installation in the Bell System's nation-wide plant. Over the years the teamwork essential to the successful carrying out of this large technical endeavor has become increasingly effective.

These organizations, functioning as a unit, turned their attention to radar in 1938 and began an expansion of effort in 1940 which continued until the war's end. Almost 50 percent of their expanded capacity was used in a complete radar service for our Army and Navy. This service was similar in so many ways to that which they normally rendered the Bell System that it was possible to expand rapidly every phase of it and to assume the responsibility from development through production for almost half of our Services' new centimeter-radar systems. The volume of equipments produced, the extent of their use, and the quality of the service they rendered on the many battlefronts of all theaters of the war are measures of the Bell System's radar contribution to victory.

Who's Who & What's What

(*Continued from page 219*)

Department. He entered the business in 1913 as chief clerk in the Commercial Department at Erie, and subsequently served as manager at Erie and Warren. In 1919 he was transferred to what was then called the Publicity Department in Philadelphia, and served successively as advertising supervisor and general information manager prior to his present appointment, which dates from 1941.

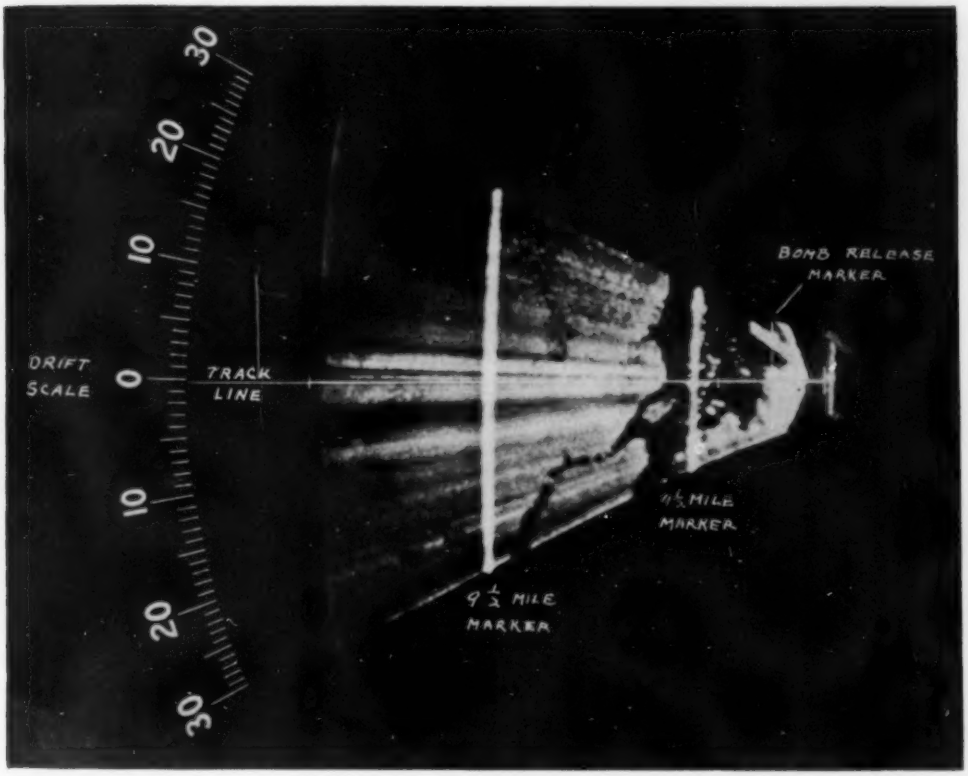
ONE OF THE most remarkable pictures ever made, this radar mosaic shows the State of Florida in scale of 1:3,999,999. It was made through overcast with Western Electric radar by Army fliers attached to Boca Raton Army Airfield, Florida

Radar: A Story in Pictures

SIX YEARS AGO, responsible persons would have dismissed as fantastic the idea of photographing an entire state through a blanket of clouds. Yet today, the production of mosaics like that on the opposite page has become routine for military men. Perhaps never before in the history of science has a development such as radar progressed with such amazing speed.

In six short war-torn years radar mushroomed into a $2,700,000,000 development and production enterprise. The many stories of its achievements—helping to save Britain during the fateful German air offensive, hunting Nazi wolf-packs in the Atlantic, curtailing the V-1 menace, sinking Japanese shipping both merchant and naval—all have implicit in them not only the factors of quality and quantity production but an intangible element more difficult to sample and appraise. It is that element in human behavior which rises in behalf of a righteous cause and transforms an almost fleeting idea into magnificent reality. No other explanation accounts fully for the radar achievement.

In the decade from 1930 to 1940, aircraft were beginning to travel with



WHEN THE TARGET comes within range, airmen switch their "p.p.i." scopes to "sector scan" (above) and bomb with the aid of "electronic cross-hairs"

AN AERIAL reconnaissance picture of the Japanese industrial city of Toyama, which turned out large quantities of ball bearings, machine tools, textiles, and alloy steels

speeds only half the velocity of sound itself, so that the warning interval which could be achieved by listening was quite inadequate. A high-flying airplane is difficult enough to detect visually even under the best conditions; and to find its range by optical means, the only pre-radar method available, always proved troublesome and often impossible. The accuracy of anti-aircraft fire suffered accordingly, and it appeared that a successful defense against hostile aircraft by fighters would require constant patrolling plus a generous measure of plain luck.

Radar made possible the timely alerting of all defenses. Fighters could be "scrambled," and then coached to an advantageous contact with the incoming raid. Anti-aircraft guns could be pointed automatically at unseen targets with greater precision than formerly characterized the sighting of visual fire.

Moreover, radar could aid greatly in increasing the impact of offensive warfare. For example, a former axiom of sea warfare had it that naval battles were decided by the factor of who happened to be "up-sun" from the enemy. With radar, our ships slugged through whole engagements in which the enemy was de-

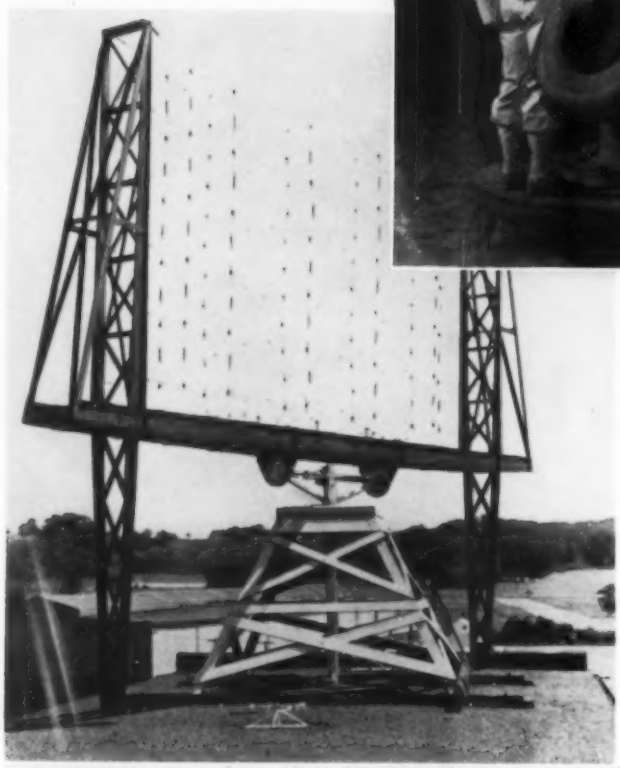
TOYAMA 90 percent aflame as the Superfortresses turn homeward on the night of August 2, 1945: the result of pinpoint bombing by radar

tected, ranged on, and sunk without a single man having seen him visually.

Before the days of radar, either "base weather" or "target weather" could bog down strategic bombing forces. By the war's end, airmen returning to fog-locked bases were talked down by means of two-way radio telephone from accurate data supplied by land-based radars. Not only could radar-equipped planes navigate unerringly to the target area; they could line up on the target and bomb blind.

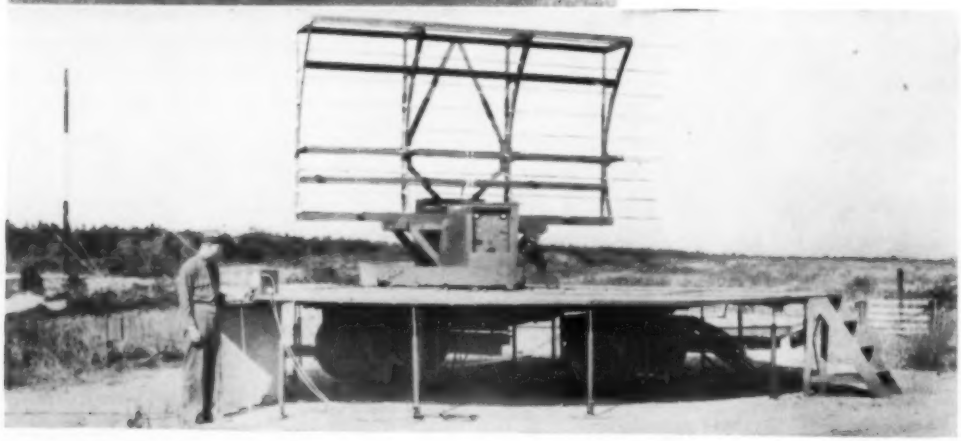
As the war drew to a close, speculation arose as to the peaceful uses of radar. It is perhaps fair to say that radar, as radar, will have an immediate and beneficial effect by adding to the safety of air and sea travel. But the impact on electronics of techniques developed during the war may well outdistance such applications by influencing developmental trends in innumerable articles manufactured for better living. Radar made the electronics industry one of America's major ones, now comparable in size to the prewar automobile industry. This new industry can be expected to create, through its enormous laboratories and factories, new channels of commerce and new opportunities in many different directions.

RIGHT: Radar's predecessor, the sound locator

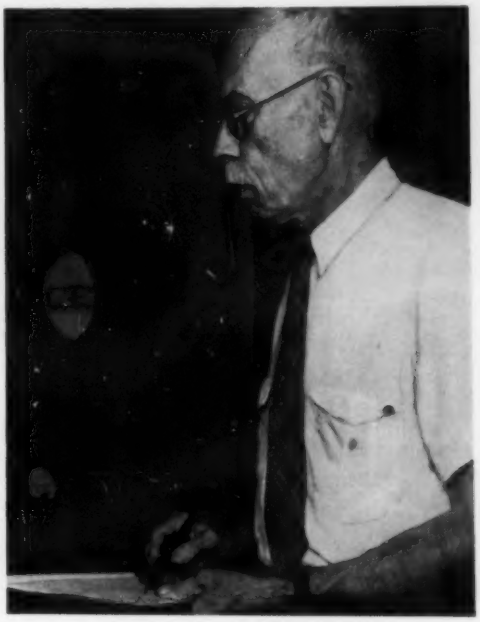


LEFT: Close-up of the U.S. Navy's first radar, a "dirigible" antenna installed 'topside' the Naval research laboratory at Anacostia, D.C.

BELOW: The Army's first radar. This prototype of the famed SCR-268 radar is shown during its initial test in the late 1930s



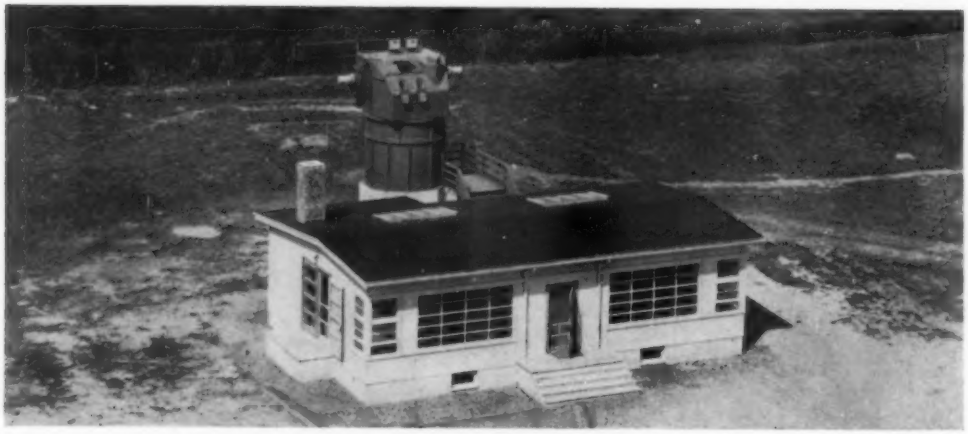
MAJ. GEN. ROGER B. COLTON (Ret)



DR. A. HOYT TAYLOR

Radar's Inventors

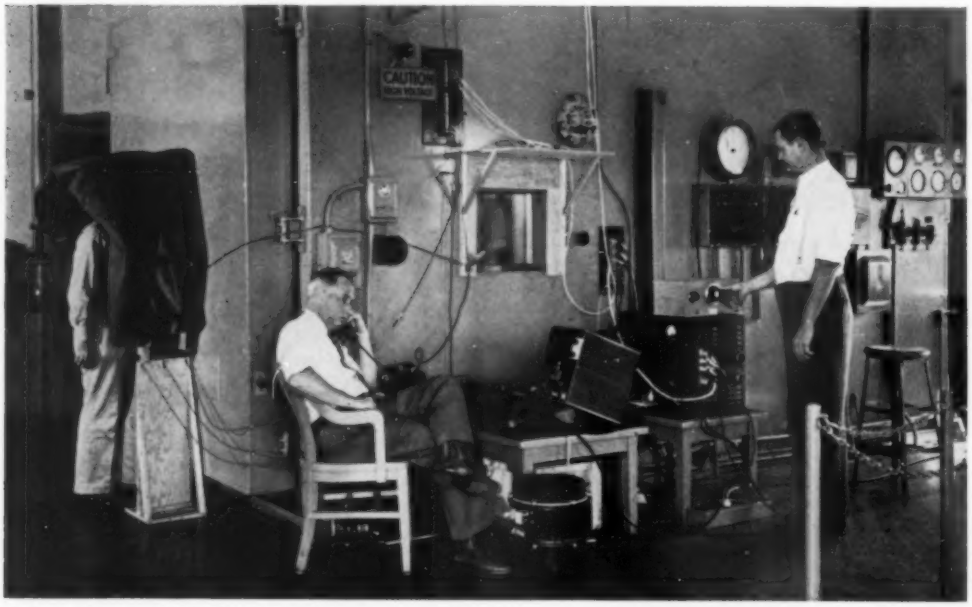
WHO invented radar? This question arises again and again. Like all exceedingly complex achievements of the present technical age, radar owes its greatest debt to the great physicists of the preceding centuries, including Newton, Maxwell, and Hertz. But among contemporary workers, whose genius turned obscure principles of science into telling adjuncts of modern warfare, a few names deserve special mention. These include Britain's Sir Watson-Watt; the Army's Maj. Gen. Roger B. Colton (Ret.); and Dr. A. Hoyt Taylor, who, as chief consultant and chief coördinator of electronics at the Naval Research Laboratory, Anacostia, D.C., made an initial discovery in 1922 which proved that radio echoes could one day, with the speed of light, serve to locate and range targets.



ODD ASSOCIATES: a neat cottage and a battleship's fire-control turret. They were among the structures which housed Bell Laboratories radar research

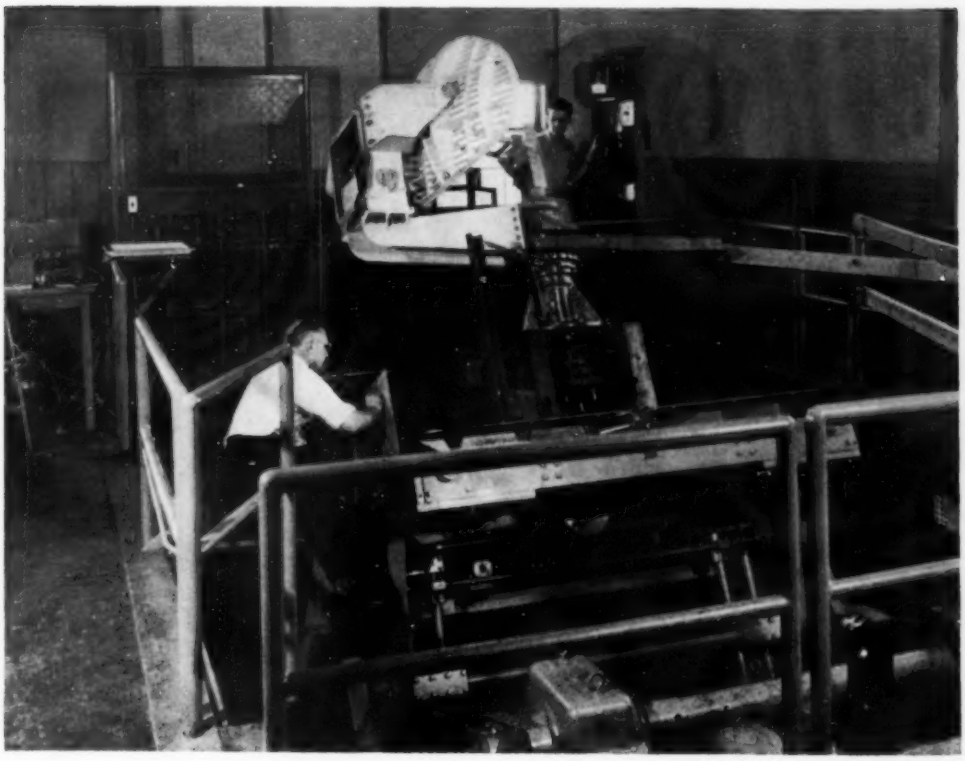
Radar Development

BELL TELEPHONE LABORATORIES and the NDRC Radiation Laboratory at the Massachusetts Institute of Technology shared leadership in radar research and development. Approximately half of Bell Laboratories' research effort during the war was devoted to radar and its contributions exceeded those of all other industrial laboratories combined.



INSIDE THIS "weather box," radar developments could be subjected to temperatures ranging from the bitter cold of polar nights to the humid swelter of the jungle

ABOVE: An experimental radar spots its first test target. Below: This testing machine simulates the pitch and roll of a storm-tossed fighting ship



AN SCR-268 radar on guard near Naples during the Italian campaign

Radar—Its Test in Battle

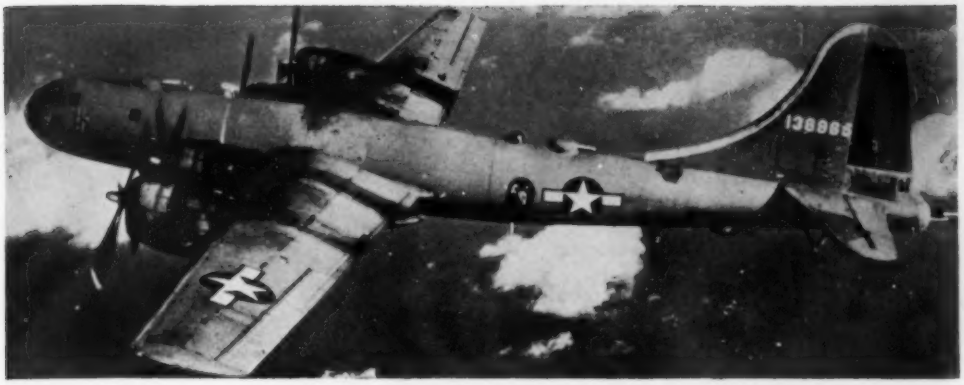
THE ASSAULTS on England by the Luftwaffe, which the British had anticipated for so long, began on August 8, 1940, and rapidly increased in intensity. The first raids were directed at RAF bases, but by September the mass raids on London had begun. England's defensive radar chain was to have its first great test. Strangely, it seemed to the British, the Germans attached no importance to the stations, although the great masts which marked each radar site afforded an unmistakable target.

Despite a critical shortage of fighter planes and pilots, the British were able to spot each incoming raid in time to throw fighters against it. The necessity for constant airborne patrols of fighters was removed and the few to whom so many owed so much were thrown into battle economically and with maximum effect. Germany suffered her first great defeat of World War II.

The battered Luftwaffe retired behind the Siegfried Line to lick its wounds, while Allied science and industry, urged on by the military, embarked on an ever-expanding program of radar production which was destined, more than any other material factor, to end the Axis dream of conquest.

MODEL O RADARS, with cradle-like antennas pointing seaward, stand watch on Okinawa

THE UNWIELDY "Giant Wurtzburg" (above), a German counterpart of U.S. land radar. Contrast it with the light, easily camouflaged U.S. search radar shown below



Radar in the Air

AMERICAN PLANES used radar for navigation; for searching out the enemy and following his movements; for intercepting his planes and directing our planes' attack; for fire control of our planes' guns; and, in addition, for both tactical and strategic bombing.

IN A B-29 (top of page) the radar operator (above) draws a radar bead on Omura, Japan, as the bombardier (right) prepares to send his bombs away

ABOVE: Action in the plotting room of a major fleet unit during the attack on Mili

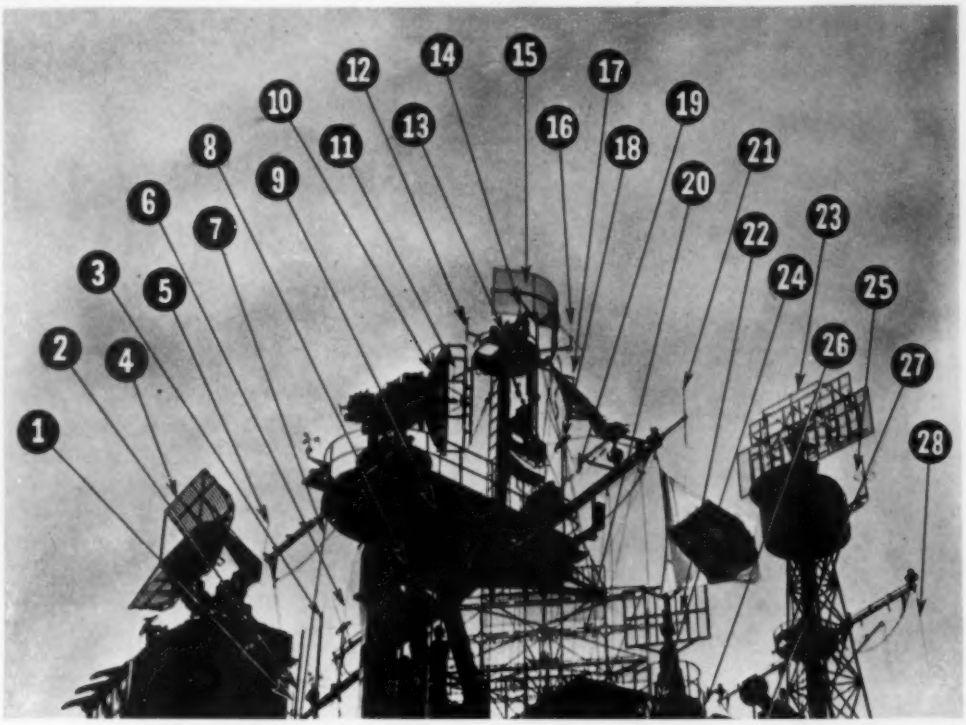
RIGHT: The wiggly line on the "A" scope (top center) shows the range of four targets

Radar at Sea

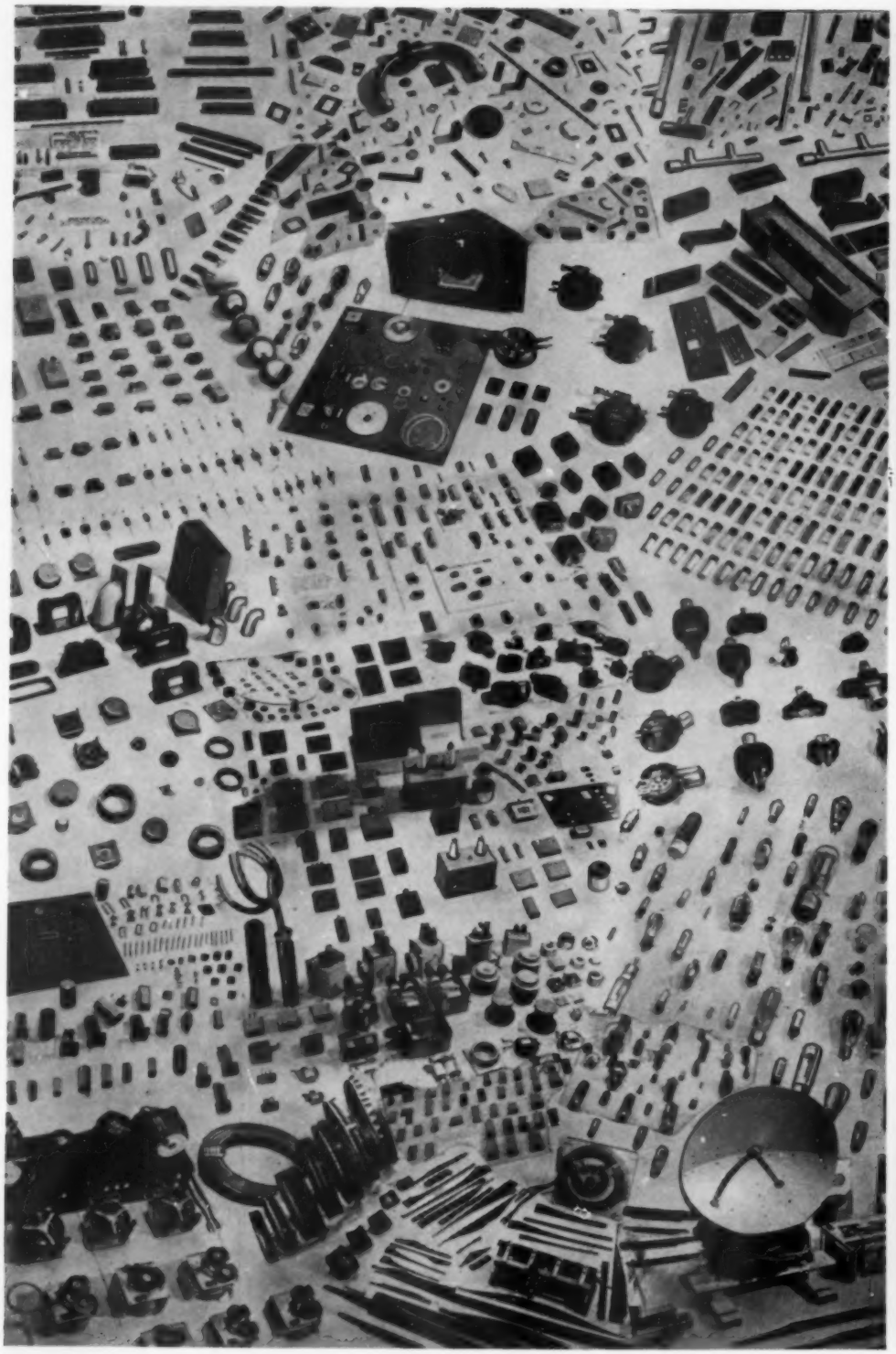
TECHNICAL COMPLEXITY, which for hundreds of years has characterized sea warfare, reached new heights in the plotting rooms of fighting ships during World War II. By radar, skilled officers recorded the positions of their own ships and planes as well as those of the enemy.

Eyes and Ears of a Carrier

THE EXTENSIVE USE of electronics in World War II is reflected in this complex array of antennas atop the "island" on a modern giant of our aircraft carrier fleet. In this view, at least 28 radar and radio antennas of different shapes and sizes are outlined against the sky. These may be identified by the corresponding numbers listed below. Circled in the picture of an Essex-class carrier at the bottom of the page may be seen the identical area shown in the upper photograph.



1. Radio communications
2. Radio communications
3. Radio communications
4. Fire control radar
5. Radio communications
6. Radio communications
7. Radio communications
8. Radio communications
9. Radio communications
10. Air search and height finder radar
11. Radio communications
12. Radar test equipment
13. Surface search radar
14. Radio communications
15. Radio homing beacon
16. Radio communications
17. Radio communications
18. Radio communications
19. Radio communications
20. Air search radar
21. Radio communications
22. Radio homing beacon
23. Air search radar
24. Radio communications
25. Identification radar
26. Radio communications
27. Radio communications
28. Radio communications



A MANUFACTURER'S-EYE VIEW OF RADAR

OFFICE of the Engineer of Manufacture, Special Products Building, Point Breeze

Radar—and the Engineer

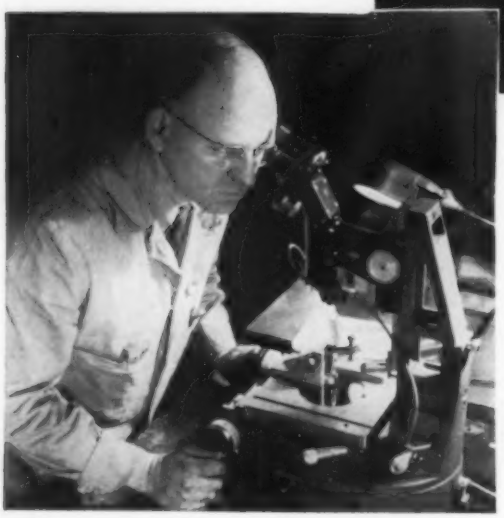
OF NECESSITY, radar required an enormous concentration of engineering talent. In addition to the thousands employed by home-front laboratories and factories, more than 500 Western Electric and Bell Laboratories engineers followed the equipment into forward military areas. By the war's end one was aboard every major unit of the fleet.

FIELD ENGINEERS in China get a home-front report on their work

Jig boring

Heat treating

Industrial bombsight



Radar Tooling

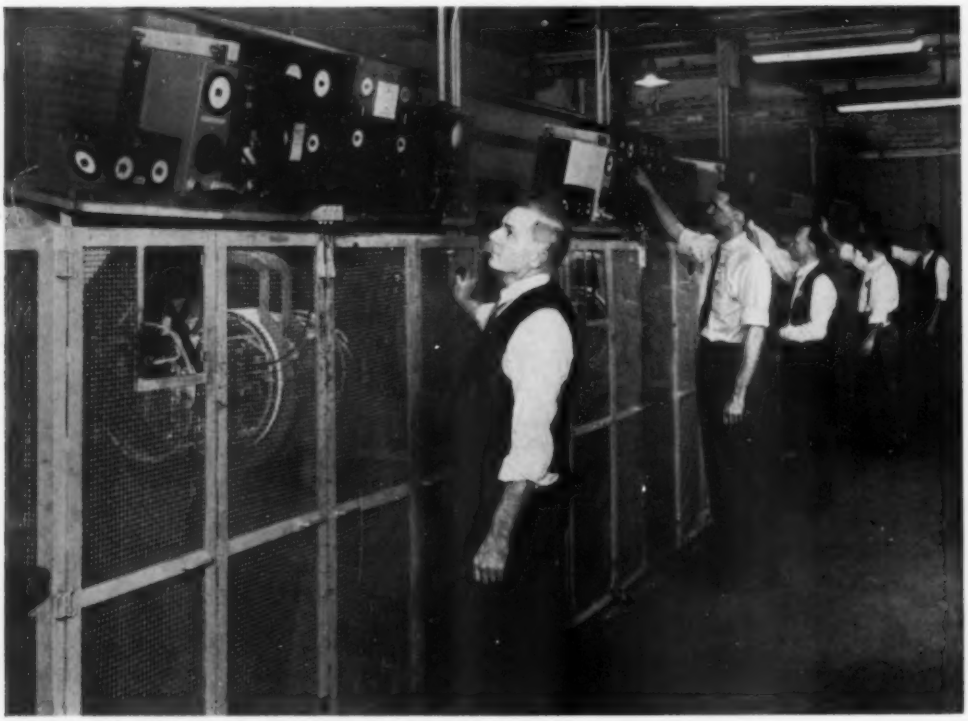
RADAR required many tools and fixtures unlike those utilized for the production of telephone equipment. More often than not, standard tools did not exist for the job. This meant the design and manufacture of new tools, a significant number of which were produced in Western Electric's own tool rooms.

THE ASSEMBLY of precision radar components required clean, well-lighted rooms

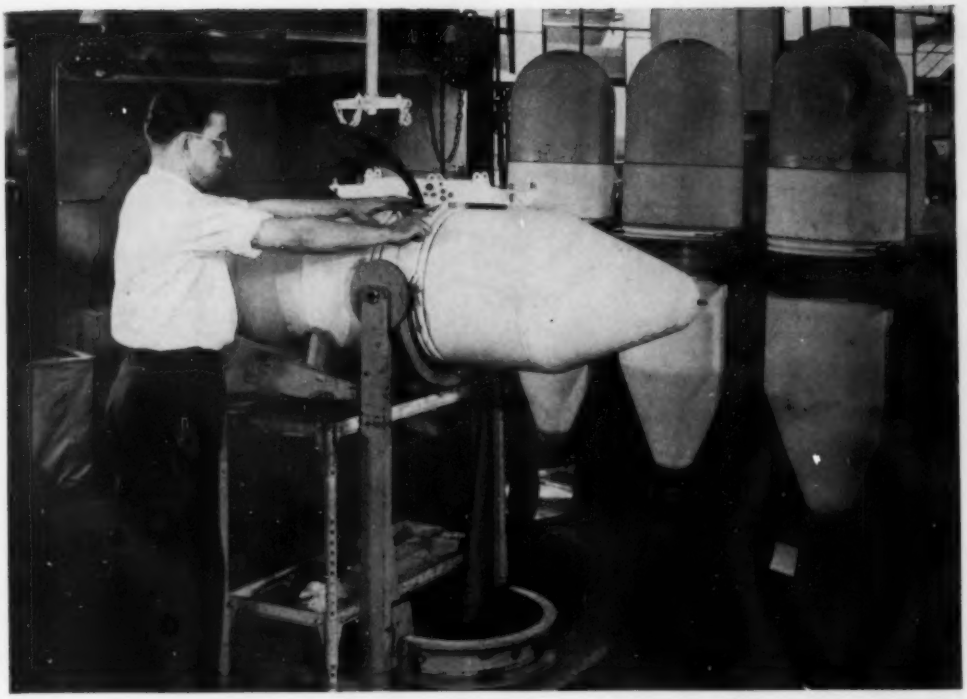
The "Ash"

"GIVE US a lightweight radar," demanded the Armed Forces, "one which can be installed quickly beneath the wings of our fighters. It should spot targets clearly up to twenty miles or more. It should weigh less than a man. Means should be provided so that it can be dropped at the touch of a button during the heat of combat. Its design should anticipate quantity production, widely divergent application, and easy maintenance." Bell Telephone Laboratories answered with the bomb-like ASH. A contract dated June 6, 1943, the largest single order received by Western Electric during the war, called for 12,500 ASH radars. This was but one of four contracts for the project, which continued through V-J day. The ASH was manufactured by Western at Hawthorne's Kolmar Avenue shop. The techniques devised for its production are representative of the most advanced practices found in American industry.

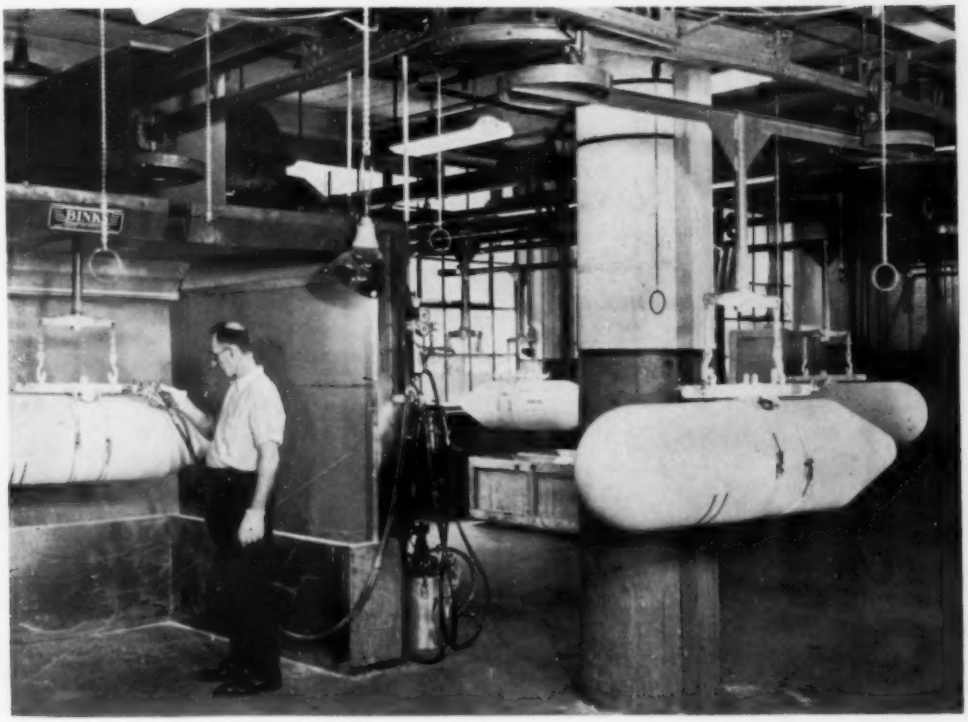
FINAL assembly and wiring of the ASH



TESTING transmitters and high voltage power-supply sets

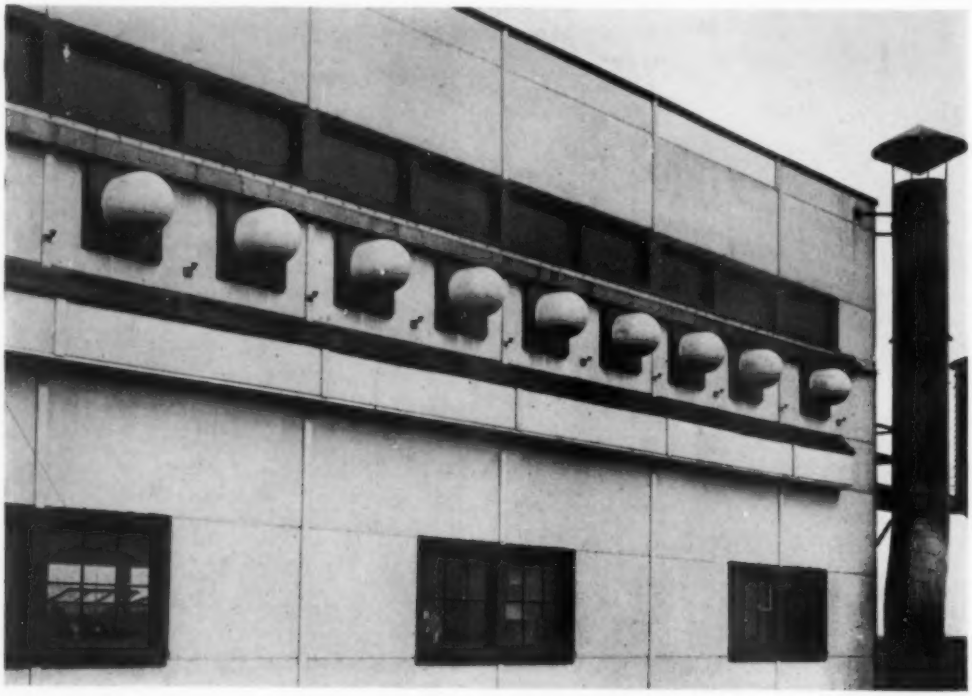


MAKING final adjustments of the suspension mechanism

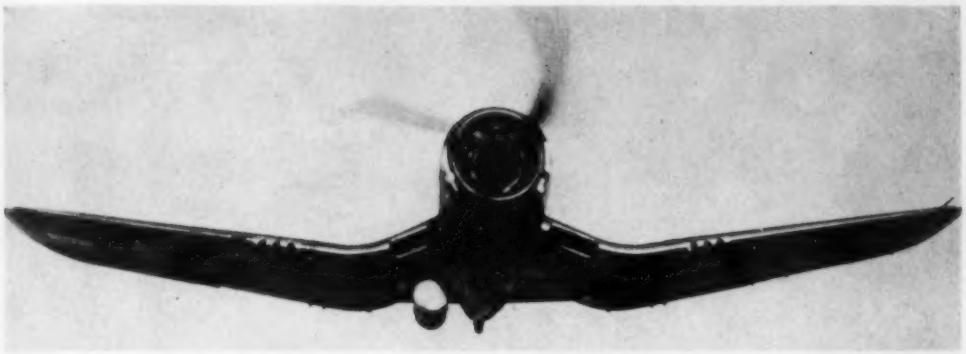


SPRAY painting the ASH

IN THIS final test room the ASH gets its first look at Chicago



RADOMES of ASH radars on test overlook Chicago targets



THE ASH as carried by three types of planes: a F4U-1D fighter; an Avenger torpedo bomber; and a Navy PTR

KEARNY WOMEN made precision bombing radars for the B-29s

HAWTHORNE WOMEN assemble "range" units for ASH radar

These Women Made Radar

THE MANUFACTURE of 57,000 radars, in addition to other Western Electric war work, meant doubling the size of the pre-war organization and integrating tens of thousands of new, untrained workers into a unit of long and specialized experience. That these newcomers to the ranks, most of whom were women, adapted themselves quickly and earnestly to new habits of work and helped the Company to break all previous production records stands as a great tribute not only to them but to the long-service employees whose coöperation the new workers so richly returned in kind.

DRILLING

HEAT SEALING

ANTENNA WIRING

ADJUSTING

APPARATUS ASSEMBLY

PIECE PART ASSEMBLY

FINAL INSPECTION

TEST SET INSPECTION

ROTATING "clip" board speeds cable forming

R. D. R.

A SHIPPING CASE encircled with a red band bearing the magic initials "R.D.R." became an object for top priority handling among merchandise and transportation experts during the war. Radar (R.D.R.) did not always leave the shipping platform in a box, however. Often long caravans of self-propelled radars left the factory surrounded by armed guards and with WAC drivers. The packaging of radar called for the utmost care and ingenuity because safe delivery required the shipment withstand every known hazard of transport and climate. Military men admonished those who packed radar, "Remember, upon arrival a radar is no better than the box it comes in."

PACKAGING B-29 antennas in airtight bags

DOUBLE-PACKING parts in cardboard containers. Below: drive-away delivery of radars

Overcoming Problems of Manpower, Materials, Facilities, and Experience, the Bell System's Manufacturing Affiliate Became the Nation's Largest Source of Radar

Radar and Western Electric

Frederick R. Lack

ONE AFTERNOON in the early Fall of 1940, a woodworker in the Queensboro plant of the Western Electric Company on Long Island fed a big slab of plywood into the whining teeth of a power saw. Probably no one at Queensboro, where the sounds and sights and smells of woodworking are a commonplace of life, realized the significance of that historic moment. Yet, as the first manufacturing operation on the first radar piece part, it marked the start of the greatest task ever undertaken by the Company—the supply of nearly a billion dollars' worth of radar and accessory equipment for World War II.

Before many months passed, the demands of the radar job permeated the Company's entire organization, even though few people knew that such a device as radar existed. Under a blanket of military secrecy the work fanned out from Kearny to Hawthorne, to Point Breeze and, eventually, spread into leased quarters scattered half way across the country. But such was the size of the undertaking that even these facilities were not enough. So, the Company enlisted the coöperation of sub-contractors—at first a few, then hundreds, and finally thousands.

Given a preparation interval commensurate with the magnitude of the job, radar would not have proved more difficult to manufacture than telephone equipment. The new technical elements introduced by radar are, of course, complex. So are those found in a modern telephone central office. The manufacture of both requires techniques and processes of great exactness. But this was war, and time was of the essence. Years had to be compressed into months and months into hours. Allied war leaders promised the continuous, 'round-the-clock' bombing of the enemy—an enemy screened, the greater por-

tion of the time, by darkness or heavy blankets of cloud. Victory, and the lives of thousands of our men, hinged on the penetration of that screen by radar without delay. This was the urgent necessity. This was Western Electric's time table.

A MANUFACTURER'S capacity to produce can be measured in terms of four interdependent elements: manpower, materials, facilities, and experience. When Western Electric was asked by the Government to undertake the manufacture of radar, the Company was more than adequately endowed with all these essentials.

It had on roll a total of 43,500 people. Its warehouses, and those of its suppliers, were stocked with just about every substance for which the mind of man had contrived a use. At its disposal were 198 acres of manufacturing space. For almost three quarters of a century, the organization had practiced the specialized arts and crafts of fine electrical manufacture and the Company took pride in the fact that throughout its history it had concentrated on manufacturing for maximum service.

Given anything like "normal" conditions for its work, the Company could count on a production potential of some $400,000,000 annually. The earliest orders for radar amounted to a mere fraction of this and, therefore, aroused no more than a flicker of interest in a few specialized departments, which were already heavily involved in building radio telephone sets for the Air Force.

Then the flood gates broke. Wave after wave of orders for equipment swept in, calling for radar of many types. The Government found in the Western, and its research and development associate, Bell Telephone Laboratories, two qualities almost unique in American industry: the ability to design and produce the precise mechanical and electrical elements required by radar; and the facility quickly to change and adapt manufacturing techniques in pace with the rapid advances of the new radar art.

The Size of the Job Which Western Did

A BRIEF GLANCE at some of the statistics of the radar job indicates the vast proportions of the undertaking.

During the war years, the Western supplied the Government with more than 57,000 radars, of 70 different types, valued at nearly $900,000,000. The Company was the nation's largest source of radar, and in dollar volume it supplied the Government with half of all the radar made in the United States. In the peak year of 1944 the Western supplied 22,000 radars, worth $340,000,000.

During the war period, the Company supplied more than 5,000 radars for use on the ground alone. Some of these were huge affairs filling several truck and trailer units which weighed up to 70,000 pounds and contained enough power generating equipment to light a small city. More than 6,000 of its radars went aboard the Navy's fighting ships where, among other functions, they pointed all of the big guns and directed the aiming of our submarines' torpedoes. Forty-six thousand went aloft with the nation's air forces, including those

which the big B-29's used exclusively for precision radar bombing.

The story of radar's development and refinement is told in a companion article beginning on page 221 of this issue. That story, like the one chronicling radar manufacture, spans a peak interval of less than five years; yet such was the activity of those years that what began as a vague hope in the minds of a handful of Army and Navy officers emerged as a multi-billion dollar enterprise with all the careful controls of a long-established industry.

"Sign Here . . . and Go to Work"

FOR WESTERN ELECTRIC, the story began in the late summer of 1938. A small group of engineers from Western Electric and Bell Telephone Laboratories visited Sandy Hook, at the invitation of the Signal Corps, to inspect a radar on test at Fort Hancock. The experimental model had been constructed under the far-seeing leadership of Col. Roger B. Colton (later a Major General and now retired) who, overcoming many discouragements and disappointments, was finally able to demonstrate the feasibility of building a mobile unit which could be used by troops in the field for detecting and ranging an airplane by electronic methods.

Impressed with the soundness of the idea, the visiting engineers promised their coöperation in furthering the development. Over the succeeding two years, they found numerous occasions for lending encouragement and active support to the project—although no formal agreement between the Government and the Company existed. That was initiated on August 23, 1940.

The afternoon was hot. Once again, at the invitation of Col. Colton, the engineers had assembled to witness the test of an Army radar—this time the model destined to become the famed SCR-268. Opportunities for additional improvement suggested themselves to the engineers that afternoon; but authority to proceed, and the necessary funds, were missing. Col. Colton drove back to the administration building and the session drew to a discouraging close. Just as the party was preparing to leave for the day, a familiar blue coupé bearing two officers dashed down the dusty roads of Sandy Hook and came to a grinding halt. "Come here!", yelled the driver Capt. (later Colonel) Rex Corput.

As one of the engineers approached the car, its other passenger, Col. Colton, thrust a large double sealed envelope from the opened door.

"Sign here, my boy, and go to work," he commanded.

GOING TO WORK meant, first of all, a further series of conferences between the technical personnel of the Army, the Western, and Bell Telephone Laboratories; the completion of a final design; and the manufacture of a preliminary model. Simultaneously, as information became available, work was started on the manufacturing analysis, a painstaking process of answering with accurate written orders and drawings such questions as: How many machine tools, jigs, and fixtures will the job require? How can the available space be utilized to effect the smoothest production flow? What kinds

and amounts of raw material? What manufactured materials and from what sources? How many men and women, and of what skills?

Although few people associated with the project understood its precise nature, all were conscious of its importance to the Government. The period of the "phoney war" in Europe had ended and President Roosevelt had proclaimed a state of national emergency. Things moved rapidly, and before many weeks the new radar makers succeeded in nursing their first production model through its myriad of detail.

LATE ONE afternoon the first SCR-268 made by Western Electric arrived for test at Fort Hancock—protected from prying eyes beneath a shroud of canvas and surrounded by an armed guard. In the meantime, at the Government's request, the Company had erected half a dozen wooden buildings on the military reservation, and the first radar was wheeled into one of these by a group of eager though nervous engineers. By the time all the gear was unlimbered, external electrical connections made, and the covering removed, the day had drawn to a close. Normally, the men would have gone home.

But excitement filled the air and work continued in the half-light of the early evening. Last minute adjustments were carefully rechecked. Then three men climbed the iron steps and settled themselves in the big bucket seats. Azimuth and elevation wheels began to turn. The great antenna swung slowly in the direction of Brooklyn.

Finally, with everyone holding his breath, the main power switch was thrown. A faint musical hum rose from the equipment, and everyone sighed with relief that there were no internal flashovers. Then, after a moment, a thin, jagged line of brilliant green darted across the face of each "scope."

"Look," exclaimed a nearby G.I., "a target . . . at . . . at . . . 44,000 yards! It must be the Coney Island gas tank."

The first W.E. radar was "on the air."

More than 2,000 of the old reliable 268s were to fight valiantly in World War II. They went ashore with the G.I.s at Guadalcanal and North Africa. Their lightning-fast waves echoed through the rugged terrain of all southern Italy. The Spring of 1945 found them helping to guard the Remagen bridge, and even today their silent watch continues over American outposts scattered throughout the vast Pacific area.

Engineering Was Never Finished

GERMANY tried to blitz her way to victory by hurling huge masses of men and machines against the Allies. She achieved the great initial production essential to this strategy through the expedient of freezing designs and employing static processes. To her leaders, this seemed a reasonable policy. But, in the end, it proved a major factor in her defeat. In contrast, our Armed Forces demanded "better and better" as well as "more and more."

Accordingly, the average life of a Western Electric radar project spanned less than a year. Even during this short interval, thousands of detail design changes were handled on a single project and, as a result,

engineering was never finished. Each radar design required a sizable engineering staff until the last equipment was shipped. Antenna spinners, for example, which are devices that help to shape radar waves into a pencil-like beam, were under constant change as the engineers sought to improve their useful life and to achieve a clearer, sharper representation of the target on the viewing scope.

Each of these thousands of design modifications, even those of a minor nature, caused, in general, other thousands of changes in the elemental manufacturing operations —or in the timing or grouping of those operations. Each change meant new manufacturing layouts, the need to relieve resulting work pile-ups along the assembly line, the necessity of acquiring new skills, new work habits, or—in extreme cases—new personnel.

The Infinitude of Radar Parts

RADAR appears different to the eyes of each beholder. To the fighting man of World War II, it was a weapon of imperative necessity. The public saw it as a dark miracle wrought by the magic of science. To the manufacturer, radar was an overwhelming complexity of intricate piece-parts.

These parts range in size from carefully fashioned microscopic specks to great castings taller than a man. Some radar designs called for assembling as many as 7,000 interrelated parts into a space no larger than a hat box. Other radar mechanisms, of the same size, demanded voids as empty as the space between the stars.

It is only by thinking in terms of these numerous and varied piece-parts, and the many individual manufacturing processes behind each one, that the true perspective of the Western Electric radar project begins to emerge.

Size, or even apparent simplicity, is no index to the complexity of a part's manufacture. For example, one vacuum tube, known to engineers as a "cavity magnetron," requires a short stubby tube of copper, the inner surface of which is uniformly pierced by a series of slots resembling precision-cut keyholes. In one model, the tube is no larger than a lady's thimble. Yet its formation required 58 separate operations. Even the metal cabinets which house the radar parts can prove deceptive to the casual eye. Many of the cabinets resemble those which cover the mechanism of teletypewriters. What appears as a simple, *single,* teletypewriter cabinet is actually made by punching, cutting, drilling, stamping, bending, forming, inspecting, assembling and finishing 225 separate parts!

What Those Parts Are Made Of

RADAR was assembled in a great variety of containers: some in pressure-tight castings; some in light aluminum boxes; and some composed of strange new materials transparent to radio waves but air- and water-tight. A long and exciting story might be written of the successful search for this substance. When finally discovered by engineers of Bell Telephone Laboratories, and fashioned with the help of the men and women of Western Electric, the performance of the new material more than justi-

fied the long search. In one form it became the "nose" of the deadly "Bat", a radar-controlled bomb which sniffed its way unerringly to Japanese shipping when loosed in the vicinity of the target by American airmen.

Many of the raw materials from which radar parts are made are fabricated in the Company's own shops. Magnetic materials, particularly of the family known as "permalloys," are produced in large quantities. Including the non-ferrous metals and their alloys—brass, bronze, nickel-silver and the like—the capacity of the metals manufacturing plant, while small compared with plants devoted exclusively to the business, amounts to 1,250,000 pounds a month.

In this same plant precious metals, measured in fractions of an ounce instead of pounds—such as gold, silver, platinum and others—are reclaimed for re-use and then recombined. To the casual visitor examining one of the products, what at first may appear as a coil of light wire may prove on close inspection to be a thin bi-metal tape composed of gold worth $35 an ounce welded to a heavier thickness of nickel worth 35 cents a pound. Such tapes permit the current-carrying springs of radar to make and break the electrical circuits without burning away in the resulting arc.

Another materials shop essential to radar manufacture specializes in ceramic products. Most of its products were developed to satisfy the Company's own exacting requirements: jewel-like colored glasses, porcelain, glazes for porcelain and metal, and materials of low electrical loss for use at the high radio frequencies demanded by radar applications.

Space does not permit even a highlight listing of all the raw material products or the shops which manufacture them. Some materials are extremely rare and have long names comprehensible only to chemists, others are as common as clay and enter into the manufacture of apparatus familiar to every telephone user.

Use of Standard Parts

STANDARD telephone apparatus, incidentally, served radar with great distinction along with more exotic components. Every system left the shipping platform with a full complement of jacks, plugs, keys, and relays. The same old reliable jacks, plugs, keys, and relays so familiar to all telephone people, they came to be the building blocks of radar.

As every telephone man knows, such apparatus must be adjusted and otherwise serviced with the help of special tools ranging from odd-shaped screwdrivers to "feeler" gauges. In the final year of the war alone the Company supplied the Government with approximately 1,000,000 of these tools made up in 150 different designs, a substantial portion of which was employed for radar servicing.

Another important class of apparatus, common to both radar and the telephone, is the repeating coil transformer or "choke". A properly designed coil of copper wire does much the same kind of work in a radar circuit as that of a wheel in a machine—it helps, among other functions, to keep the machine running smoothly and enables power to be transmitted effectively from one part of the mechanism to another. During the last full year of the war the Western

made 9,300,000 of these "electrical wheels," valued at $42,000,000, and, in addition, purchased 3,000,000 more from other manufacturers. Only part of them went into radar; yet the consumption of radar coils ran into millions.

So great did the need for coils become that a special coil shop was established in a former shoe factory at Haverhill, Mass. The project was undertaken with only a skeleton force of experienced people, who then trained 2,000 others recruited locally. In a few months the new shop was winding, insulating, potting, and testing some 8,000 types of standard coils. Within a year 770 new kinds of coils were introduced into manufacture.

MANY OF these new coils were exceedingly complex. A simple coil of open construction had formerly been used in one part of an airborne radar circuit. This coil had the advantage of light weight, small size, and low cost; but it had the disadvantage, under tropical conditions, of susceptibility to moisture and fungus growth to a degree which could not be tolerated. Weight considerations precluded sealing it in a metal can. After an extended hunt, the Laboratories' engineers came up with a compromise. Beginning with talc (the base of face powder) and the oil of cashew nuts, they concocted a black viscous liquid. Large pumps circulated this between mixing vats and the tanks of a special dipping and drying machine.

An automatic conveyer transported the radar coils through the bath and an air drying cycle and finally delivered them to a constant-temperature oven. In this oven, the chemistry of the black liquid underwent a radical change, which engineers call polymerization, and the light-weight coil emerged, still a light weight, but incased in a thin though amazingly tough armor—a match for the climate of any battle area.

In all, Western Electric set up 16 satellite plants in nine cities to assist its main plants in turning out land, sea, and air radars of seventy different kinds ranging in size from huge multi-ton jobs to those for aircraft weighing no more than the pilot of the plane.

In Baltimore, the broad interior of a former airplane factory soon became an orderly patchwork of work benches, office areas, engineering cubicles, and tool cribs. Carloads of raw material entering the hangar on one side rolled out the other as giant ground radars, each supported by 30 heavy truck tires.

The former shoe factory in Haverhill shared its radar load with a former laundry in Jersey City, and with what had been an ordnance plant in Eau Claire, Wisc. Ex-garages, warehouses, engine-parts plants—almost any building with a roof that did not leak, or which had one that could be repaired—qualified as a radar shop if the community could provide people enough to staff it with workers. By the war's end the Company's total manufacturing space had increased to 329 acres.

Women Helped to Solve the Manpower Problem

THE NECESSITY of recruiting and training additional manpower to meet the demands on Western by the Services was felt early in the war. Suffi-

cient men, with or without manufacturing experience, were not available. Hence the Company turned to women.

In 1873 Western's first woman shop employee took her place at the work bench. Through the years her numbers grew, and by 1941 the Company could take pride in the fine record of accomplishment made by three generations of women employees. In 1941, women comprised about 20 per cent of the total employment. At the time of maximum wartime employment, August 1944, when the total reached 97,416 employees, the proportion of women had increased to 60 percent. At no time during the war did the number of male employees rise substantially above the peacetime figure. In effect, men employed and trained for radar production and other war work served as replacements for the 28,000 released to the Armed Forces and Merchant Marine.

THE THOUSANDS of newly employed women who made radar ranged in age from schoolgirls to grandmothers and in experience from housewives to actresses. Prior to the war, few of them had ever visited a factory, much less worked in one.

Although no set formula exists either for removing the complexity from a strange piece of radar gear or for endowing a pair of unskilled hands with the deftness of long practice, the Western's manufacturing engineers found that almost anyone can learn quickly to perform three or four simple operations, particularly if the same sequence is repeated over and over at intervals of about a minute or so. To utilize the services of these new people effectively, the Company intensified two long-established programs; one involved work simplification, and the other, training.

To qualify these untrained women for radar production, therefore, the Company's engineers analyzed, grouped, and timed all of the elemental operations through which bits of raw material became finished piece parts. Then, step by step, they continued the process as piece parts merged to form sub-assemblies, as sub-assemblies combined into final assemblies and the whole finally evolved as an enormous complex of electronic fighting gear, tested and often packed specially for duty overseas.

The Importance of Sub-Contracting

IF, EARLY IN THE WAR, the Company had not undertaken a far-sighted program of sub-contracting, it would have been swamped by the influx of Government orders. To facilitate sub-contracting, each major Western Electric location surveyed the manufacturers in its area to ascertain the type of work for which they were best qualified. The surveys covered more than 6,000 firms: a few very large ones, and the remainder employing from one or two people to several thousand.

To most of the sub-contractors, radar represented a far cry from peacetime pursuits. A manufacturer of slot machines, for example, turned out a light-weight precision antenna for an air-borne radar. The manufacturer of cabinets to house the radar which controls the firing of the biggest guns on the heaviest battleships was formerly a maker of metal clothes lockers. The precision antenna drive for a large ground radar came from a maker of laundry ma-

chinery. A producer of pots and pans made tail sections for the bomb-shaped radar carried beneath the wings of air fighters. The metal frame for this same radar came from the shop of a bicycle manufacturer in Chicago. Finely made mechanical parts came, surprisingly enough, from a nationally known cereal firm, which maintains a precision machine shop for the peacetime production of packaging machinery. The requirements for aiming a large radar accurately are not unlike those demanded by astronomers of their big telescopes. The manufacturer of the mount for the giant 200-inch telescope atop Mt. Palomar made antenna mountings for Western's ground radars.

SUB-CONTRACTING, of itself, made heavy demands upon the organization. The Company found long ago that it is not possible to place an order either in its own shops or with another manufacturer and then merely wait for schedules to be met. During the war the meeting of Government schedules became supremely important. The Company would be told that a battleship intended to drop anchor in a certain harbor for repairs on a specified date. During the repair interval, usually short, the Navy wanted to install a new radar which would permit new and improved tactics on the next mission. Any failure to meet the delivery schedule on the new equipment might force the ship to rejoin her fleet without it and delay the use of these new tactics, with the possibility of losing all the advantage of surprise.

In embarking on its program of subcontracting, the Company made a careful study of each firm's qualifications: the nature of its experience, peacetime product, and plant facilities. Radar work appropriate to the firm's capability would then be allocated and Western would supply out of its own facilities and experience such help as the project required. Subcontracting thus became a matter of industry-wide team play, in which thousands of workers all over the nation pooled their skills and resources alike, to the end that Allied fighting men should bear arms of a quality second to none.

Many Western Electric engineers and production men were assigned to subcontractors' plants, and their assistance proved invaluable. In addition to the more conventional technical aid, these men spent many long evenings in plants waiting for parts to be produced so they could be raced by air through the night to some distant factory for the next step in the production process. Occasionally the job meant fighting bad weather and transportation delays. When the blizzard of 1944 tied up the freight yards in Cleveland, Western's men plowed their way through the bitter night, opened the stalled box cars, and after a long search located packages of parts required by a subcontractor the next day to fulfill an urgent war project.

Contouring the Cat's Whisker

SOME OF RADAR'S tools and processes proved startling even to Western Electric men of long experience. The contouring of the "cat's whisker," is a case in point. The rounded end of the cat's whisker, a tiny filament of metal thinner than a hair and only a

fraction of an inch in length, makes contact with a pinhead speck of special crystal. The combination replaces a vacuum tube in the ultra-high-frequency circuits of radar and millions of them were required by the services.

The end of the cat's whisker must be pointed, but not sharp, something like the point of a slightly used pencil. If too sharp, the point bends or breaks. If too blunt, it presents an improper pressure to the crystal face, and refuses to work. Every stunt in the book was tried in an effort to produce just the right contour, but all ordinary methods failed. Finally, the engineers resorted to an old and almost forgotten trick of radio amateurs called electrolysis, an electrochemical process by means of which a metal can be quickly dissolved in a liquid through the passage of a carefully controlled current.

At first the idea seemed as simple and logical as a-b-c. Dip the cat's whisker into the solution, turn on the current, and let nature take its course! When all the metal disappeared except that covered at the surface of the solution, the job would be done. Unfortunately, there was a catch. The proper contour required an absolutely motionless liquid. And the liquid refused to stop jiggling.

The answer to this complication was found in 45 tons of concrete—sunk fifteen feet to bedrock and insulated from local highway and railroad vibrations. A 45-ton tool for a .001 ounce product!

RADAR'S high electrical frequencies —some measured in terms of billions of cycles per second—made the positioning of circuit elements extremely important. Deviations in the location of one part from its prescribed relationship to other parts may easily cause the values of a radar circuit to fall outside specified electrical limits.

Special tools were designed and built to facilitate the shaping of the lead wires which support resistors, capacitors, and other circuit elements of radar. These ingenious tools cut leads to precise length, produced the required bends accurately, and partially formed the connecting loops. Assembly and wiring operators found that parts so prepared could be soldered into correct position easily and quickly.

Moreover, with the aid of these tools, beginners could perform the precise cutting and bending operations. Thus, by building skill into the tools, the valuable time of many long experienced workers was conserved for other important essentials of radar wiring.

The Importance of Testing

THE STORY OF radar testing in itself could occupy many printed pages; for, regardless of the care with which the equipments are built, the exacting attention lavished on the preparation of manufacturing specifications, and the fabrication of parts and their assembly and wiring, the product remains an inert mass of parts until its various circuits have been carefully combed by ingenious test sets and subjected to the scrutiny of the expert testers who operate them. Whether in the factory or in the field, a blank radar screen may carry one of two interpretations: there is no target, or the system is not working.

In 1944 alone, Western Electric

produced more than 36,000 testing units for the Army and Navy, exclusive of the equipment used in the factories. These test sets were standard with the Services for use with systems of all makes.

The accuracy of some of this equipment defies comprehension. An oscillator, which generates electrical impulses of extreme rapidity, is made with such care that a clock of proportionate accuracy would run nearly a thousand years before gaining or losing a second. But, at the same time, an oscilloscope had to be produced which, dividing a millionth of a second into little parts, checked this extraordinary "clock" for errors! The only fact more astonishing, perhaps, is the realization that these sets are largely a product of feminine hands which, less than five years ago, were required to accomplish nothing more exacting than the artful application of make-up.

The Company's war record continues on and on with such examples of technical ingenuity. Yet, without one additional element, that record would mean little.

Throughout the war, military leaders reminded the home front that the pace of the assembly line, not the High Command, would establish "H" hour and "D" day. Battlefront strategy, they emphasized, began with manufacturing schedules.

Normally, such schedules are based on carefully compiled statistics. But radar was a new art. No time table had been written. Hence, the rule became—give the Armed Forces what they want *when they want it* and substitute determination for the missing figures.

The office of Western's president and the shipping platform alike obeyed the watchword: meet or *beat* the schedule! Each week on Tuesday afternoon, production heads would meet with the president to review the status of all projects and devise means for cracking stubborn bottlenecks. In office and factory, the men and women of the Company gave the best of their hands and brains so that no American fighting man should lose his life for want of a Western Electric radar that did not arrive on time.

The record for 1944 is typical:

DELIVERIES IN 1944 COMPARED WITH SCHEDULED COMMITMENTS

Class of Equipment	*Percent Realization*
Airborne Radar	102.6
Ship Radar	102.8
Gun Directors	100.

What Is Radar's Future?

SINCE V-J Day, the question has often been asked: How will radar serve the arts of peace, and what contribution can the Western make to its advance?

Numerous applications already have been suggested for radar in the field of transporation. Airliners need no longer bow to the whims of weather, and weather prophets can probe the skies for hidden storms which heretofore have threatened shipping. Radar can lead vessels into fog-bound harbors and point out the many hazards which menace navigation. Had the ill-fated Titanic of a generation ago carried radar search gear, she could easily have found safe passage through the ice fields of the North Atlantic.

Of still greater value may be the indirect applications of radar's tech-

nology. The Bell System recently demonstrated a multi-channel system of radio telephony which promises great economies in extending telephone service to areas now isolated by water or difficult terrain. The circuit re-arrangements and electronic components of the new system are greatly indebted to radar. The new Bell Laboratories development for making speech visible to the deaf employs components closely related to some of those in radar. Television, electronic calculators, automatic warning devices . . . the list of possibilities seems endless.

But whatever usefulness the future may contrive for radar, none will eclipse the attainments of its recent past. With radar, our fighting men emerged triumphant. How much dearer might the cost of victory have been without the help of radar?

THE MEN AND WOMEN of the Bell System, through whose toil and skill the miracle of radar was so largely wrought, may—and do—have a proper sense of pride in the true worth of their accomplishment. They face the future with long experience now enriched by the lessons of a new technology. Just as radar has already begun to plumb the vast expanses of inter-stellar space, so will these men and women continue their explorations in the limitless realm of science and from their findings build a greater telephone system for the greater America of tomorrow.

Panic on the Telephone

AFTER three long years in the African and Italian campaigns, Doctor Joe was on his way home. When his wife, Myra, heard the exciting news, she began planning just what she would say when that first precious telephone call came through after the ship docked. The call had to be perfect. But the more she tried to tailor some appropriate remarks to fit the little wedge of talking time, the more panicky she became.

Finally, in desperation, she appealed to her cousin, a young lieutenant just back from overseas. Would he phone her a few times and help her rehearse? The lieutenant laughed at her. "Why there's nothing to it," he said. "Look. When the call comes through, you'll say, 'Hello darling,' and Doc'll say, 'Hello, darling, how are the children?' And you'll tell him they're fine, and then the talk will go zooming on from there. It's a cinch."

Two nights later, the New York operator asked Myra if she would accept charges on a call from Doctor Joe. After a long, tense wait, there was his voice.

"Hel-LO, darling!" Myra caroled.

"Hel-LO, darling!" boomed back the doctor.

Then he got stuck, she got stuck. Silence. Panic-stricken, Myra wildly recalled the lieutenant's formula. Into the phone, she shouted, "Darling, how are the children?"

And Pappy Joe, who had been away three years, yelled dizzily, "Oh, fine! Just fine!"

—MARJORIE STOLL.

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Getting Telephone Service Quickly to the Many Who Have Waited a Long Time for It Is the Bell System's Biggest Emergency Restoration Task

The Bell System's First Order of Business

Harold S. Osborne

MORE THAN 2,200,000 telephones were connected by the Bell operating companies in the five months starting last October. That is by far the biggest number ever installed by the System in a comparable period.

And the trend is upward. Connections in December were 440,000. In January they were 487,000. The February figure was 491,000.

Net telephone gain—the balance after disconnections are subtracted from connections—is the highest in history. In that five-month period it was 1,140,000. Currently it is running at the rate of 3,600,000 a year.

These figures are evidence of tremendous accomplishment. They demonstrate the pace being set by the Bell System in its drive to give telephone service to waiting customers whose orders have been unfilled because of wartime shortages of facilities.

Coupled with the day-to-day tasks of providing and improving the nation's telephone service, this emergency program is the Bell System's first order of business. It will continue to be so until the last waiting customer has been served and telephones for everyone are once again being installed promptly on request.

Providing telephone service for all who want it, when they want it, and the way they want it is the normal responsibility of the Bell System. The System had met this obligation fully and pridefully until the telephone went to war. But in the years when victory was the first order of business, and telephone materials and equipment were needed by the Armed Forces, a huge backlog of unfilled orders piled up. With V-J Day, Bell people everywhere swung into an emergency program to clear these held orders with all possible speed.

And it is a real emergency—the greatest in Bell System history—more

IN MANY A Western Electric distributing house, old switchboard sections, removed from manual offices after dial conversion, are being reconditioned to go back into service in other manual offices to help relieve the equipment shortage

extensive than any ever caused by flood, fire, wind, or sleet. It's nationwide. It's fundamental. It's intricate, complicated, and tough to overcome.

The peak in held applications for main telephone service, 2,170,000, was reached last September. At that time more than 900,000 were "held initially for instruments" and the balance of more than 1,200,000 for the lack of central office equipment and outside plant.

Since then, the volume of new orders has broken all records. On top of all those held orders, nearly 2,000,000 *new* applications for main telephones have been received in those five months—almost half of them in the first two months of this year—and there is no let-up today. Many of these new orders have been filled for customers who qualify for preferred treatment under the order of precedence established by the Government. Others have, of necessity, been added to the waiting list.

Concurrently, service has also been provided to a substantial proportion of the customers who have been waiting a long time. But because of the new orders received since the war, the total waiting list is still very large —more than 1,900,000 on March 1.

As more and more telephones are installed, the margins for growth which have existed in many central offices and cables have been used up. This in turn has brought about a substantial increase in the the number of customers who, although qualifying for preferred treatment under Government regulations, have to wait for service because of lack of facilities.

Their applications now constitute more than ten percent of all held orders. And such applications must be filled ahead of those from customers who do not qualify for preferential treatment under the regulations.

The manufacture and installation of hundreds of millions of dollars' worth of telephone plant to fill hundreds of thousands of orders for telephone service is not an over-night process. The time factor in many cases is not weeks but months.

That's the situation the Bell System is fighting today with every weapon in its peacetime arsenal.

Western Electric Turns to Peace

AFTER V-J DAY, the Western Electric Company moved in record time from large-scale production for the Army and Navy to large-scale production for the System telephone companies.*

Western is now turning out telephones at the highest rate in its history: 14,000 a day.

It is now producing dial central office equipment at maximum pre-war capacity—1,000,000 lines a year—

* See "Western Electric Tackles The Peacetime Emergency," MAGAZINE, Autumn, 1945.

IN MANY PLACES there is a neck-and-neck race between facilities and service. Here an operator is handling calls at a position for which the multiple is only partially completed, while installers are working on still another switchboard section

This business has lived and grown successful and of good repute by giving service.

It has given the public what it wanted when it wanted it, and done it with efficiency and courtesy—and then invented better things and taught the public to want them and ask for them.

That is what made this business something more than just a business.

It made it a good place to work, a good life to live, something with a little distinction.

It did its best to serve the public.

That paid off when it was comparatively easy to do.

Well, now it is hard—what about it?

What do we do?

Shall we run the business for our convenience?

Shall we run it to meet some long distance "prove in" rules?

Shall we serve our engineering studies?

Or shall we serve the public?

What is the objective?

To give people the best possible service as cheaply as we could do it.

But the "service" comes before the "cheap."

And not just to serve those we found it convenient to serve.

Our job is to serve every single person that we possibly can, and get service to them as fast as we can.

That may mean putting plant in and taking it out again in a little while.

What did we do after the hurricane?

Did we wait until we had everything engineered for 1960?

We did not.

We got something going fast and improved it afterward.

and expects to step up this rate until it reaches 2,000,000 lines this year.

It expects to ship at least 1,400,000 lines of dial apparatus in 1946.

Cable, wire, and other items essential to telephone service are being produced at pre-war levels or better, and production is still rising.

Western Electric also is obtaining telephone equipment from other suppliers and from Government surplus. Facilities no longer required in military establishments and war plants are being recovered for civilian uses.

Through the Western, the Bell System was successful in bidding-in the first lot of surplus telephone equipment which was sold by the Reconstruction Finance Corporation. This consisted principally of some 15,000 standard Western Electric combined telephone sets and a quantity of standard lead-covered cable. The System's purchases of surplus equipment have totaled nearly $2,000,000 to the first of March.

With the coöperation of the Armed Forces, more than 138,000 Bell-owned telephones no longer needed in government-owned ordnance plants and military esablishments were removed between June and December. About 1,000 Bell-owned manual and dial P.B.X. switchboard positions were similarly recovered in the same period. The Associated Companies also are purchasing small lots of war surplus materials directly from the Signal Corps when usable items become available in their territories.

All of this material has been or is being rushed back into service for civilian users.

Western Electric's Hawthorne Works had some 600 equipment engineers at work on the lay-out of new

dial central office equipment for the Companies at war's end. Now it has 500 more—and the group is still growing. The engineers are working six days and two evenings each week.

So the Companies are going to engineer small step-by-step dial central office additions themselves, just as they do small manual jobs.

On larger dial installation jobs the telephone companies are working out other ways to lend Western a helping hand. Some companies find it feasible to send their own equipment engineers to Hawthorne to engineer certain jobs. One company thus saved the Western's engineering force 135 man-weeks of work.

Special off-the-job class-room instruction to supplement the training of Western Electric employees who install central office equipment began immediately after V-J Day. By the end of the year more than 3,000 men in 40 cities had had this supplementary training—and this program is constantly being stepped up.

In March of this year there were more than 10,000 on the Western Electric equipment installation force, an increase of some 6,000 since Japan surrendered. By the end of the year this force will be built up to 22,000, and will require about as many supervisors as there were installers on the payroll in the middle of 1944.

THE WHOLE emergency program is geared for high speed. High-speed restoration work uses up extra money the way high-speed driving uses up extra gas. But telephone people have a goal to reach in a hurry. They figure the money cost is cheap in com-

Well, this is just like the hurricane, but a whole lot worse.

What did we expect—to have the worst war in history and have it result in the millenium of ease and comfort?

The phrase "the war is over" is an hallucination as far as we are concerned.

The war has just got to our front.

This is our big time, and if we are not going to throw away all the ideals of our history we are going to take off our coats and show the world what we can do in a fight.

Are we going to degrade service a bit for the many to give service to a few more?

Sure we are.

We are going to give everyone some service just as fast as it can be done, and we are going to tell everyone exactly what we are doing.

This is no time for little faith, or half-way measures.

It is time to strain every effort to give service, and a time for full explanation of what the facts are.

Take a vote.

Ask the public, do you want telephones now or a little saving later and a perfect engineering record?

Maybe we don't face those questions in those words.

But we do face those questions.

And I have no doubt what the answers are.

The question is how good a job do we do.

How much of lasting satisfaction do we get out of recognizing the biggest and hardest job we ever had, and licking it.

From a statement, "What We Think about Held Orders," by Arthur W. Page, A. T. & T. vice president in charge of the Information Department.

parison with the value of being able to give service as promptly as possible to everyone who wants it and needs it.

War Experience Proves Helpful

THIS BUSINESS operates through tried and tested methods and practices, developed and perfected through the years. But it recognizes also that unusual circumstances sometimes demand unusual actions.

During the war, the Bell System added three million telephones, needed for the war effort, with relatively little additional plant. It reconditioned and installed nearly a million old telephones which normally would have been junked. It made other telephones out of parts which were made available, and converted telephones from one type to another to meet special needs. It increased the load on central office equipment by five and ten and even 15 percent above that for which it was designed with ordinary standards of service. It devised ways to utilize the local cable plant more completely.

The experience gained during the war in the use of expedients and the application of ingenuity is standing the System in good stead now.

Old type telephones have been reconditioned, for example; surplus coin telephones have been converted to wall sets; and manual desk stands have been converted to dial.

AN experienced telephone man instructs two high school boys in the fine points of installation, which they will be able to apply on customers' premises during their out-of-school hours

ADVANCE WIRING of subscribers' homes gets everything ready to connect telephones just as soon as they become available. Here a customer and his small daughter watch the process approvingly

One company devised a combined set, for use where the bell boxes could not be fastened to walls, by mounting a hang-up set and bell box back-to-back on a wooden base.

Another company, needing magneto wall sets to furnish service in rural areas, sought out and purchased more than 2,000 from farmers. They had been discarded when farmers' service-station lines were cut over to community dial operation several years before. It didn't take long to recondition and put them back in service.

Telephones Were the First Need

AS OF THE END of last September, 900,000 applications for telephone service were held solely for lack of telephones, in locations where central office and cable facilities were available. Between then and March 1, Western Electric—thanks to its remarkable reconversion job—has shipped to the Bell operating companies more than 1,200,000 telephones.

At the same time, those companies have been building up their installation forces to put those telephones into service for people who have been so eagerly awaiting them. During 1945, 15,600 employees who had been on leave of absence to serve with the Armed Forces were welcomed back, and more than 10,500 veterans of World War II who had not previously worked for the Bell System were hired. This happy process is continuing.

Newcomers to the business are teamed with experienced employees and sent out on the job, to "do while learning" as well as to "learn while doing" so as to get on with the work as rapidly as possible. In many instances, employees who formerly were installers have been transferred to that work temporarily from other less pressing assignments.

Several companies have been using groups of less experienced installers to "pre-wire" premises of applicants who were scheduled to get new telephones as soon as a shipment of them was received from Western Electric or when additions to the equipment in central offices were about completed. Usually "pre-wiring" includes all of the work required on a customer's premises except the installation of a telephone set.

At least one company used such a group as a flying squadron to install telephones anywhere in its territory. There are 60 members of this group, almost all of them new telephone men recently released from the Armed Forces. They are made up into five squads, ready to go to work installing service for those on the waiting list the minute the equipment situation makes it productive for them to move into an area.

In another area, high school boys have been trained in certain installation procedures, and are sent out in taxicabs during their free hours to help pre-wire customers' premises.

By such expedients as these, as well as by the more usual methods, the Associated Companies have built up the rate of installation to keep pace with Western Electric's production of telephones. Applications "held initially for lack of telephones only" have been practically eliminated; the System companies are receiving tele-

MEMBERS OF A specially organized "flying squadron" of installers receive instructions before moving into an area where equipment is now available to serve those on the waiting list

phones for installation in substantial and increasing numbers; and this important part of the whole problem is well in hand.

Central Office Equipment Too

AS OF EARLY SPRING, at least 80 percent of all held applications for service are unfilled because of the lack of central-office equipment. That makes this the most important factor of the whole emergency program, and gives office, or to connect customers from one office area into another one by utilizing spare trunk conductors or placing new trunk cables. In many cases equipment has been taken out of one office and re-installed in another where it is more urgently needed.

Is one office short on line circuit terminations? Then increase the telephones on the party lines until every line is handling its full quota of parties, even if the pairs serving parties

Station wagons have been adapted to serve as installers' trucks

ingenuity the opportunity to work overtime in an effort to give service to more customers—sooner.

With so many offices loaded to the gunwales, any office which has a small margin of equipment over the immediate demand for service provides a challenge to the engineer. He has found several ways for capitalizing on it. In a large city it may be possible to transfer customers in a boundary area to the less congested have to be connected together in the central office itself.

Perhaps the dial operators' positions can handle a little more traffic. In that case, lines can be connected for manual originating service, while calls to those subscribers will be completed through the dial equipment.

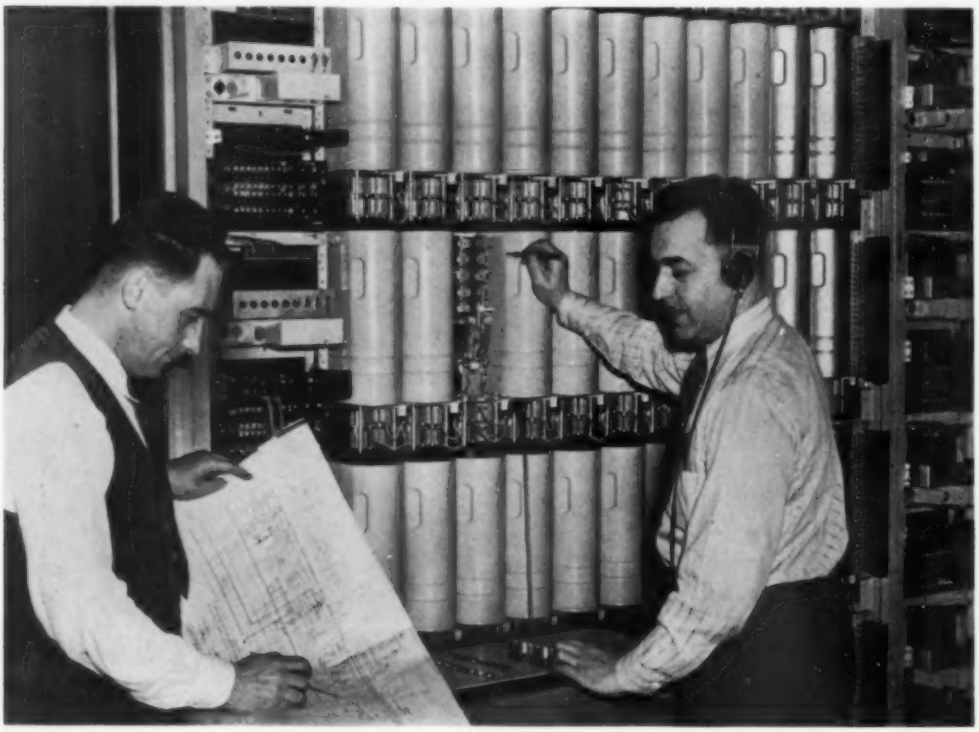
Most offices are short on terminal numbers. How can every number work all the time? Assign a new customer to any disconnected number as

soon as it is released. The new subscriber will get some calls intended for the old one. But that's much better than no service at all.

At the same time, the terminals used for testing purposes are being cut to the barest minimum, and the same is done with the numbers used for company business.

Means have been devised for making a single dial number terminal do double duty, serving to reach two customers on the same party line.

As new equipment is produced, the use of every frame and switch is planned with the utmost care. Ways have been found to drop out 15 percent of the equipment in new cross-bar offices temporarily by cutting corners and eliminating every frame not immediately essential to service. The provision of equipment for growth in service after cutover has been reduced to the bare minimum needed to carry on until the next addition can be



THROUGH an ingenious re-arrangement, this bank of step-by-step dial central office switches is temporarily serving twice as many subscribers as it was designed to take care of

Has a block of numbers been assigned for coin box growth? Cut it to the minimum and use the numbers thus released for regular service. Likewise, go ahead and use numbers that have been saved for growth in business P.B.X. groups.

rushed in. A few frames here, a few switches there, may not sound large; but if you can defer them and still give service in a hundred jobs, it means that perhaps ten new jobs, otherwise impossible, can be squeezed in.

Typical ground rules for the engineer are:

Since party service can get by with less equipment than individual, plan for party.

If you can possibly do without a test frame, leave it out.

If you can use a small manual position in place of a large one, do it.

Installing new central office equipment takes time. There are thousands of wires to place and solder. The quicker it can be done, the sooner service can be given; and new installation schedules have been worked out to use maximum manpower and double shifts, thereby shortening the time the installation requires from 15 to as much as 30 percent.

Just as customers' premises may be pre-wired, so cable racks and cable may be placed in advance, in order that as soon as the factory can get the equipment on the job, wires will be waiting to be soldered to it.

Distributing frame jumpers are laid in place ready to solder.

Test procedures that intervene between the completion of an installation and the connection of new service are cut to a minimum.

There must be no lag; when the equipment is ready, service will start.

Buildings Are Needed

IN SCORES of localities throughout the System, either new buildings or substantial additions to present structures must be erected before additional central office equipment can be installed.

Erecting a building today is a tough job. It takes something more than know-how. It takes *determination*. One has to make up his mind he's *going* to build it, come hell or high water. Then he has to imbue the architects and contractors with the same spirit.

The companies are tackling the job that way, and it works. They have also found they had to reverse many usual procedures. Instead of drawing plans and then buying materials, they have sometimes had to buy what materials were available and then modify the plans to fit them.

If bricks for additions don't match those of original structures, what of it? A vine can be planted or a rain spout located to cover the break where the color changes. If doors and windows don't quite match those in the original structure, who cares—just so they open and shut? If only cinder blocks are available, O.K., cinder blocks are used for inner walls and the exterior faced temporarily until bricks can be had.

Never mind if the plans aren't finished, go ahead and dig the basement. Equipment on hand before the building is finished? Then knock up temporary siding, and start the installation as soon as the inside is finished and the outside is weather-tight. Days too short to meet the completion date? Rig up flood lights and work nights.

That's the way the Bell System builds buildings in this emergency. Costly? Of course! But effective.

Making Every Cable Pair Count

OUTSIDE PLANT, too, is getting the same emergency treatment. Nothing

new is added unless and until all existing facilities are "full-up." When they are, short cables often are placed to transfer pairs from full feeder cables to others in which there are spares.

Government surplus cables purchased by the Western through the R.F.C. are used where they can be made to serve—even in unorthodox ways. If it's the only kind available, cable designed for submarine installation may be placed underground; cable made to be buried may be strung aerially in place of plain lead cable; two 11-pair cables are strung together instead of a single 26-pair cable; quadded toll cables are introduced into exchange plant.

Cable troubles are cleared when they occur. Normally, spare pairs are provided for growth and for maintenance. It is often more economical to maintain service by merely transferring to a good pair when one goes bad. Now the need is for more working pairs in existing cables, so every effort is made to keep all pairs working.

All cable-placing projects not incidental to or part of the emergency job are postponed "for the duration."

Tools and Vehicles Needed

ALL SORTS of ways are being found to augment war-depleted vehicle fleets. Companies have purchased second-hand trucks and passenger cars, and have rented their personal cars from employees and construction trucks from other utilities.

Some of the companies have recently received a few new truck chassis. Since bodies weren't available, they built stake bodies and mounted pole derricks and winches on construction-truck chassis, and bolted pick-up bodies on installation-truck frames.

In order to make one motor vehicle do the work of several, half a dozen men are often assigned to an installation truck. These men work in a limited area and the truck keeps them supplied and moves them from job to job.

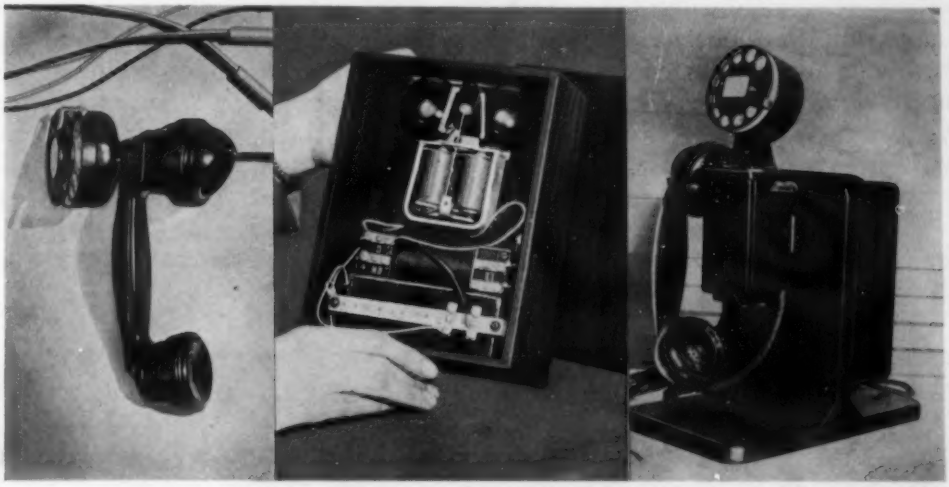
OUTFITTING the fast growing installation forces with hand tools and test sets has also taken a bit of doing. Every possible source of tool supply has been tapped, including local hardware stores,. auto accessory shops, and mail order branch stores. Local supply people, working closely with Western Electric buyers, have made local purchases of thousands of such items as pliers, screwdrivers, hammers, bits, braces, star drills, axes, and hand saws.

Installers' tool bags have been on the shortage list. Since leather is scarce, heavy canvas bags are being substituted. One company found it could get plenty of canvas bags made up by an awning manufacturer while his business was suffering its usual mid-winter slump.

"Make-do" dial test sets are being produced by Western Electric distributing houses. These are being assembled out of old handset handles, dials, and other standard parts produced for other uses. One house turned out five hundred for use until the standard rubber encased type is available.

And that isn't all. Here and there throughout the System the companies have been:

Taping worn or frayed telephone cords, so that most of the production



WHILE THE shortage of telephone instruments was acute, some make-do models were put together which can't be found in any catalog. Left to right, above, are, a dial test set, a wooden box for the subscriber set, and a back-to-back arrangement of a hang-up telephone and a wall bell box

of new cords can be used to equip new telephone sets;

Recovering protectors as well as instruments when telephones are disconnected, to alleviate the shortage in this item of equipment;

Using home-made connector blocks and ground rods to overcome temporary shortages;

And saving, reconditioning, and reusing everything with any life left in it.

All Departments Speed the Job

THE DRIVE to get service to waiting customers in the shortest possible time affects most directly, of course, the Plant and Engineering Departments and Western Electric. But all departments are making important contributions to the effectiveness of the job.

The business offices, which have custody of the held-application files, are also custodians, in a sense, of the System's good repute among all who want service and have been unable to get it. For it is here that detailed records of service applications are maintained and it is the business office people who must keep those files up to the minute, must answer the anxious and sometimes skeptical inquiries of waiting applicants, and must, as facilities become available, make sure that the applications are filled strictly in their proper turn.

Now that facilities are becoming available in larger quantity, special arrangements have been worked out for issuing service orders so that the Plant Department can put into use without delay the facilities to provide service to applicants whose turn has been reached. But before an order can be issued for the installation

of any telephone, a check has to be made with the applicant to make sure he lives at the address given and still wants service. At present, more than 70 percent of the applicants on the waiting lists still want service when it becomes available to them.

This checking frequently is handled by special groups of new employees who have received short specialized training courses in this phase of the job. This helps to relieve the work load on the more experienced representatives, who are busy handling the unprecedented volume of applications for and inquiries about service.

The directory people, too, have had to find ways of keeping up with a greatly increased volume of work without sacrificing any of the accuracy which is so essential in compiling directories both for public use and for the use of the information operators.

Traffic people are seeking and finding ways to speed the job. The desire to provide service for everyone has become an important part of the fundamental objective of giving the "best possible service". Traffic engineers and general engineering people are increasing their usual close relationship. One department in effect "looks over the shoulder" of the other at work in progress, so that ideas can be exchanged and modified without waiting for completion of plans to

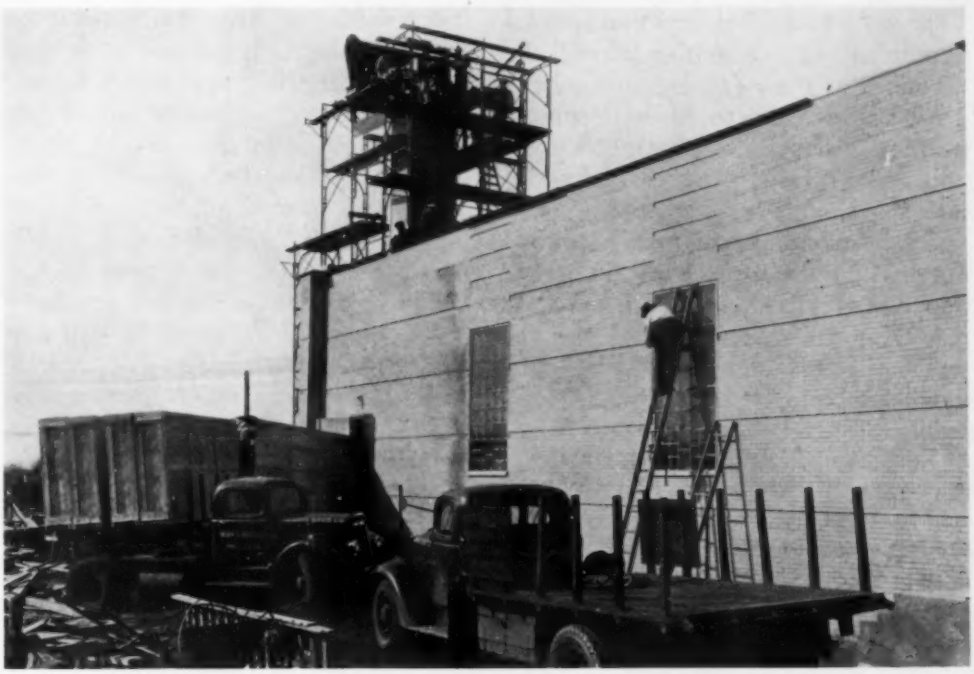
THERE'S NO WAITING for Spring weather here. Work on an addition to this telephone building progresses in spite of winter storms and low temperatures

the last detail. Frequently, they find it possible to postpone certain time-consuming details for later action in order to get on with the job.

Continued emphasis is being placed on recruiting new operators, and it is expected that the System's operating force will be increased by 60,000 during 1946—more than twice the increase in any previous year. Special training positions, ordinarily a part of the regular switchboards, are being provided to permit full scale training away from the switchboard, thus making possible the full use of existing facilities for service to a constantly increasing number of customers.

All these efforts to get service to many people quickly increase the volume of work in the Accounting Departments, which keep the records of customers' accounts and prepare all monthly statements. Accuracy and speed are essential in this work, which for efficiency is organized on a production-line basis calling for coördination and teamwork at every step.

To keep pace with the huge volume of new accounts, it is necessary to carry on a continuing program of recruiting and training new sorting clerks, rate clerks, toll billing typists, toll ticket sorting clerks, and other important personnel in the intricate organization which is Accounting.



NEW DIAL equipment is unloaded for installation while work on the exterior of the building is being completed

These new people must be assigned to productive jobs as rapidly as possible but without impairing the operating efficiency of the offices.

Reporting on Our Progress

BELL SYSTEM workers are busy—too busy to stop and talk much about their accomplishments. But the people of America are entitled to know how they're getting along.

When you add to the numbers of people still on our waiting lists all the members of their families and all the friends who want to be in telephone contact with them, you've got a sizeable segment of America's total population.

So the telephone companies are reporting on their progress, in newspaper advertisements and articles, magazine advertisements, on the radio, in letters and pamphlets, window displays, posters, bill inserts, public talks, and other ways.

Employees are kept informed so that they can answer queries correctly. Also, it's just good sense to answer the question: "How're we doin'?"

The companies are answering that in bulletins, in their magazines, in booklets, at employee meetings, on posters, pay check inserts, and in similar ways.

The unprecedented situation of very many customers waiting for a telephone service which can't be given them immediately presents a challenge to the Bell System. Rising to that challenge, telephone men and women everywhere voice a resounding second to the pledge made last Spring by Walter S. Gifford, president of the American Telephone and Telegraph Company:

"We pledge the American public that after the war or as soon as materials and supplies become available again, we shall do everything in our power to speed the day when all who want telephone service can get it and, what is more, can get the type of service they want and as much of it as they want."

"SERVICE TO THE NATION IN PEACE AND WAR" is the tradition, the constant purpose and the daily work of the Bell System. From Pearl Harbor to V-J Day, the System met the continuously increasing war communications needs of our country, and its experience in overcoming war difficulties gives further assurance that it will meet the needs and opportunities of peace. Today and tomorrow its welcome task is to make telephone service better than ever before and increasingly useful to more people. . . .

Today, in the aftermath of war, the nation is exploring its resources and working toward a new equilibrium. The problems of human and physical readjustment have closely affected the Bell System as they have all business. These problems demand—and they are getting—the utmost effort in order to insure the rendering of good telephone service all the time. The management of your Company was never more mindful of its duty to meet its public service obligation fully and to see that the message gets through. It looks forward to providing more service and better service, more jobs and better jobs, than ever before.

From the A. T. & T. Annual Report for 1945.

Consolidation of Keystone System with Bell Company of Pennsylvania Eliminates an Uneconomic and Inefficient Situation in Only Big City Where It Had Continued

Dual Telephone Service Ends in Philadelphia

Peter L. Schauble

IN PHILADELPHIA, third city in the land, 43 years of duplicative telephone service came to an end early one Autumn morning of 1945.

At 7 A. M. on Monday, September 17, fuses were pulled in the central offices of the former Keystone Telephone Company, cutting off the power supply and silencing the Keystone telephone system, while at the same moment circuits were closed in several central offices of the Bell Telephone Company of Pennsylvania to provide new or additional Bell service to former Keystone subscribers.

Philadelphia had been in recent years the only large city in the country in which two telephone systems have rendered service side by side. The events of that September Monday morning, bringing to a climax long months of preparation, construction, and installation, thus marked the ending of an epoch.

Starting service in 1902, the Keystone Telephone Company's operations were centered in Philadelphia. It operated approximately 45,000 telephones and seven dial central offices in that city, and a few hundred telephones in suburban territory in the Pennsylvania counties surrounding Philadelphia. Through associated companies—the Eastern Telephone and Telegraph Company and the Camden and Atlantic Telephone Company—it also operated about 5,000 telephones in southern New Jersey.

In Philadelphia, Keystone service was concentrated in the business districts. Its slogan long had been, "When the Keystone Rings, It's Business," and it actually served fewer than 500 residence subscribers.

The company had had practically no main station growth in the last 20 years of its existence. It had never paid any dividends on its com-

mon stock, and it was in arrears on dividends on its preference stock by about ten times the designated annual payments.

More than 93 percent of the 13,000 Keystone subscribers also had Bell service. The Bell Company, at the time it acquired the physical properties of the Keystone company, operated approximately 465,000 stations in Philadelphia.

"LET 'ER GO!" Connected by telephone with all the central offices involved, Carl R. Freehafer (left), vice president and general manager, Eastern Area, Bell Telephone Company of Pennsylvania, gives the order which consolidates Bell and Keystone service in Philadelphia

Preliminary Steps

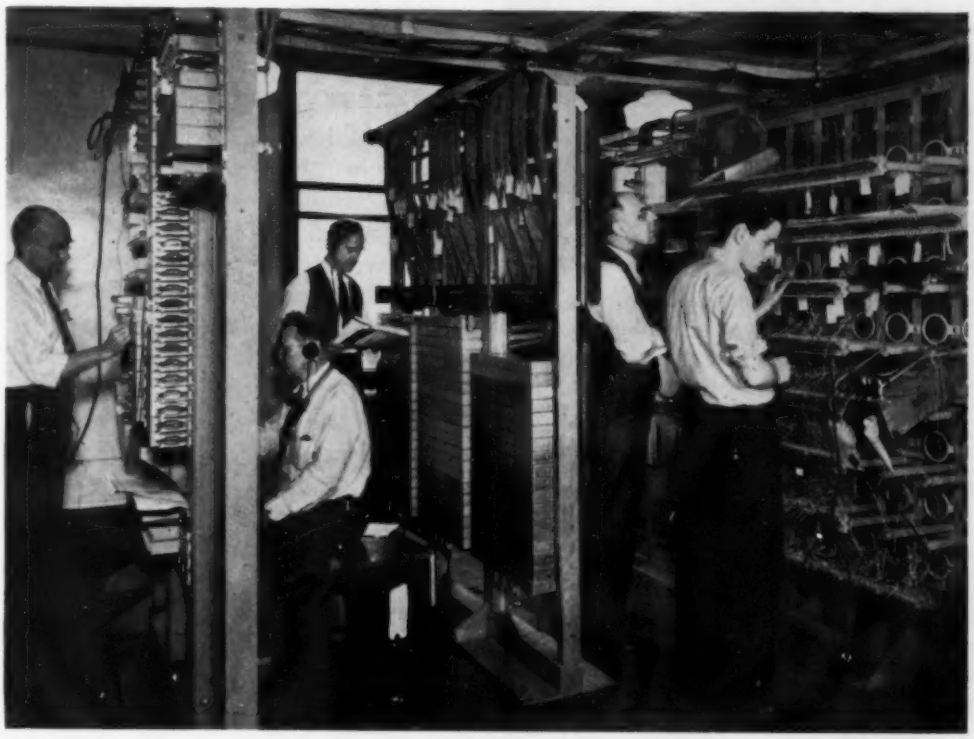
THE FIRST STEP in the purchase of the Keystone system was an agreement between New Jersey Bell Telephone Company and the Gary interests for the purchase by the New Jersey Company of the stock of Imperial Securities Company, a holding company which controlled the three Keystone operating companies. On January 30, 1941, the New Jersey Company filed an application with the Federal Communications Commission asking its approval of the purchase of this stock. An amended petition was filed on July 23, 1942, in which the Bell of Pennsylvania joined, asking that approval also be

given to the purchase of the physical properties of the Keystone system by the two Bell companies.

The FCC held seventeen days of hearings in 1941 and 1942 and took 1,449 pages of testimony. It approved the proposed purchase in March, 1943, stating that consolidation "will be of advantage to the persons to whom service is to be rendered and in the public interest."

"Users within the competitive areas are inconvenienced by the necessity of having two telephones in order to obtain comprehensive service, and in selecting between such telephones in calling other persons who subscribe to only one of the services," the FCC order stated. "This dual service involves duplication of line and line structures, central offices, and telephones and duplication of costs for maintaining and operating separate facilities whose function could be served by a unified plant.

"We find . . . that disadvantages to particular users which may result from this program of acquisition and consolidation proposed by applicants are outweighed by the benefits to the



WESTERN ELECTRIC installers at work on the frames of a new dial private branch exchange system being installed in a large Philadelphia bank to replace a combination of Bell manual service and a private dial system which connected with Keystone

FIFTY-TWO HUNDRED service orders were written in Pennsylvania as a part of the consolidation program. Here, one of them is going by teletypewriter to the test center involved

general public to be served and the advantages of increased efficiency, convenience and comprehensiveness of service which may be expected to follow. . . ."

The Commission also pointed out that the conservation of materials essential to the war effort was another important factor. It was estimated that about 1500 tons of copper and smaller quantities of other critical metals would be released by the unification.

Following approval by the FCC, the New Jersey Bell Company acquired all the stock of Imperial Securities. F. F. Addicks, general plant manager of New Jersey Bell, became president of the Keystone Telephone Company of Philadelphia, and a number of the new directors and officers were Jersey Bell officials.

A meeting of the Keystone stockholders was held on June 22, 1943, to approve the sale of the physical properties to the Bell companies, to give up the company's telegraph rights—a necessary step under Pennsylvania law—and to dissolve the company after the sale of its physical properties was consummated.

Subsequently, applications were made to the regulatory bodies of the two States involved. In Pennsylvania, the Public Utility Commission held two hearings—at which comparatively few objections to the proposed consolidation were raised. It was testified at the hearings that while increased telephone costs would result for some few Keystone users after the consolidation, the majority would save on their telephone bills. It was estimated that the net annual over-all decrease in costs for users of Keystone service would be in excess of $100,000.

Both Commissions approved the project, the Pennsylvania Commission stating that the merger would benefit both Bell and Keystone subscribers and that it would be of long-range benefit to the public.

Special Organization Set Up

AFTER LEGAL DETAILS of the sale were completed, the Bell companies took over the physical properties of the Keystone system in the Fall of 1944. At that time Keystone had 394 employees in Pennsylvania—66 of them in the armed forces—who were taken into the Bell of Pennsylvania organization with full credit for the length of their Keystone service in benefits, pensions, and similar matters.

Preparations were begun immediately for consolidation of the two systems. Keystone telephones in Pennsylvania, meanwhile, were operated as the Keystone Division of the Bell Company.

A consolidation committee, made up of personnel from the departments involved, prepared plans for the consolidation and cut-over. This was supplemented by a cut-over committee, in charge of the execution of plans.

Engineering groups studied the available types of Keystone equipment, to determine which could and which could not be used for Bell service. These studies resulted in the retention of Keystone handsets, some special switchboards, and a certain amount of other equipment. The general plant supervisor's forces developed maintenance practices for this equipment, and training of maintenance personnel was done by Bell field forces.

The sales organization began the task of interviewing the approximately 13,000 Keystone subscribers, making surveys of the equipment in service, the subscribers' telephone needs and usages, and arranging for the issuance of service orders in connection with the necessary installation of additional Bell equipment and rearrangements of existing equipment.

TO PROVIDE sufficient Bell service to take care of the expected demand meant that additional equipment had to be installed in various Bell central offices. Because of Keystone's concentration on business service, it was found that the greatest additions would be needed in the Lombard central office, located in the center of the city, and the Regent central office, in the industrial northeast section.

At Lombard, where the largest installations were made, it was necessary to add two sender frames, two link frames, four district frames, two line finders, and one office frame; and 1,200 subscriber lines, 213 final selectors, and 190 dial impulse repeaters. In all, seven Bell offices required additional central office facilities, and a large number of outside plant rearrangements and additions were necessary. A total of 1,134 work orders to construction forces were issued for outside plant work.

All of the large Keystone subscribers had duplicate service. This meant that in some cases, where Keystone usage was light, only very slight additions to subscribers' facili-

CUTTING OFF the life blood of the Keystone Telephone System: Mr. J. W. Root, retired, Keystone's oldest employee, pulls the fuses at Keystone's Race central office

ties had to be made to the Bell installations already in place. But in many instances this was not true, and neither the Bell nor Keystone installations were large enough to handle the combined traffic expected after the consolidation.

IN SOME INSTANCES, new Western Electric facilities were available for replacements. But in a number of cases these problems were solved by a complicated exchanging of equipment, so that a Bell or Keystone switchboard removed from the premises of one customer was reconditioned and installed for another customer, while the first customer might receive equipment formerly used by still a third subscriber.

As an example, before the consolidation one large subscriber used a 6-position manual Bell switchboard, serving 483 telephones, and a subscriber-owned one-position dial PBX connecting with Keystone lines and serving 623 telephones. The subscriber-owned Keystone telephones were used very largely for interior service. In unifying the service, subscriber-owned facilities were purchased and a new 4-position Bell dial PBX was installed, with 629 telephones. In this case, new Western Electric PBX facilities were available, and the older equipment was removed, modified, and re-used for other subscribers.

Another complicating factor was the large number of so-called "trader boards" operated by Keystone, and used by more than 100 large subscribers, most of them financial houses. This was a special development using large amounts of lamp and key equipment and private lines. Some of these "trader boards" used as many as 60 lines, connecting both with the central office and with perhaps 25 other subscribers over private lines, and having as many as ten operating positions. An intricate network of private lines was thus involved. These arrangements were taken over virtually intact. The former Keystone service was, of course, confined to Philadelphia and nearby subscribers; but after the cut-over it was possible to add several leased lines to New York and other outside points for some of the "trader board" users.

The large number of leased lines provided by Keystone to telegraph companies, fire and burglar alarm systems, and wired music firms also meant extensive rearrangements of plant. Keystone had approximately 3,500 such lines. It was necessary to make entirely new circuit arrangements in most of these cases, so that the services provided by the two systems could be coördinated into one without interruption to service.

EASING THE WAY toward the final consolidation was an agreement with many large subscribers, prior to consolidation, that as soon as additional Bell facilities were installed their Keystone service could be discontinued. Practically all of the large PBX users who required new switchboard installations had thus been transferred to complete Bell service prior to September 17. Because of this, and normal disconnections in the year before the final cut-over, when no new Keystone subscribers were added, the number of Keystone telephones in service dropped from 45,300, at the time Bell took title to

the system, to approximately 22,400 on last September 17.

In summing up after the unification program had been completed in Pennsylvania, it was found that 5,200 service orders had been issued, resulting in a net increase of approximately 5,000 Bell lines and 12,000 of the Pennsylvania Company, and from the Keystone Division, to assist in the program, and they worked long hours of overtime to complete the tremendous installation job. They were assisted by Western Electric installers, who handled the additional central office equipment and

For part of its 60 miles, the old Camden & Atlantic open-wire toll line ran through swamps accessible only to men equipped with rubber boots

telephones. Fifty-eight dial PBXs had required modification or replacement and 412 new switchboards had been installed.

Installation Problems

A total of 164 people were recruited from all over the territory the work on the larger dial PBXs. The regular forces in the Accounting and Directory Departments also performed a sizable job in handling the necessary changes in billing and listing records.

Because of the large number of changes in the PBX equipment, it

was necessary for the Traffic Department to conduct an extensive training program for PBX operators. All operators affected were visited by Bell traffic representatives, and were given comprehensive training where new switchboards had been installed or where old boards had been modified to any large extent.

erators the day of the consolidation.

For the comparatively few individual and party-line customers who had no duplicating Bell service, it was necessary to make new Bell installations, connecting Bell lines to Keystone instruments where they were re-usable and then inserting heat coils in the Bell circuits at the time of the

ABOUT 120 TONS of copper wire were salvaged from the Camden & Atlantic line. Pictured is one of five carloads shipped to the Nassau Smelting and Refining Company

Prior to the cut-over, the large users had been provided with additional Bell lines. Some of these were so arranged at the central office that they could be put in service by inserting heat coils in the circuit. In other cases dummy plugs were placed in the trunk jacks on the PBX switchboards, which were removed by op-

cut-over. Then, at the proper time, it was necessary only to close the circuits in the Bell offices, while in the Keystone offices the fuses were removed, shutting off the power.

Usable Keystone instruments were modified by providing new dial face plates and new number plates, the latter having the Bell numbers un-

derneath with temporary Keystone plates on top, which were removed by the customers after the cut-over.

THE CLIMACTIC MOMENT came promptly at 7 A.M., with Carl R. Freehafer, vice president and general manager, Eastern Area, in charge. Stationed at the Lombard central office, he was connected by telephone with all the other offices affected, and his "let 'er go" was the signal that ended dual telephone service in Philadelphia.

At Keystone's Race central office, the fuses were pulled by J. W. Root, oldest Keystone employee, who had taken part in the inauguration of Keystone service in 1902. Now retired, Mr. Root came back for the final job.

A few minutes later the Keystone offices were virtually deserted, the switchboards and dial apparatus silent for the first time since their installation in 1921.

Although it is planned ultimately to replace all former Keystone station equipment with standard Bell System facilities, a considerable number of instruments have been modified and re-used, as well as a number of PBX systems. The net gain in usable instruments is estimated to be about 13,000, and these are being reused throughout Pennsylvania.

The PBX equipment not re-used is being sold through Western Electric, and both the central offices and their associated equipment are also being disposed of.

Due to the shortage of facilities at the present time, every effort was made to re-use all possible equipment. However, because it would be necessary to maintain repair parts stocks for equipment manufactured by several different companies and to train men in repair work, plans have been made to retire nearly all former Keystone equipment as soon as practicable after the facilities shortage ends.

New Jersey Bell's Part

MEANWHILE, the New Jersey end of the physical consolidation had been completed on the morning of March 13, 1945. The Keystone system (Eastern Telephone & Telegraph Company) operated in and around Camden, and in Cape May County in the extreme southern tip of the state; and while the New Jersey Bell Telephone Company's task was numerically smaller, it presented its own share of difficulties.

The Camden part of the job was relatively simple. Of the 1,500 Keystone telephones there, all but perhaps 300 of their users also had Bell service, and for them it was merely a matter of eliminating the Keystone service. There still was room at Bell switchboards to accommodate the remainder.

In Cape May County, however, the situation was different, and the consolidation was termed by veterans a harder job in some respects than some of the Company's major dial conversions had been. The problem was how to add a substantial number of new customers from Keystone switchboards to Bell central offices already at capacity loads and in buildings into which extra equipment, even if available, could not have been jammed with a shoehorn. Diligent consideration of all possibilities evolved a plan for interconnecting

the Bell and Keystone offices at Wildwood, and also in Cape May city, so that local service between the two boards in each case could be obtained with normal operation, and toll service completed as though the two offices were tied together, through the use of a common numbering system.

Small Keystone offices at Sea Isle City and Cape May Court House were closed and their customers were transferred to Bell offices. Bell and Keystone offices at Dennisville and Woodbine, serving roughly the same areas, were continued in operation. A midget dial office at Villas was continued and later was replaced with a larger dial unit.

A unique Plant job was removal of the 40-year-old toll line linking Philadelphia and Camden with the Jersey shore area for the Keystone system. Some 1,400 miles of copper line wire, weighing about 120 tons, was removed and salvaged, 7,800 crossarms on 2,900 poles were removed, and 1,400 of the poles were taken down. Many poles were in swamp land inaccessible except to construction men on foot and wearing hip boots. Working conditions were hazardous. Much of the line flanked a heavily traveled main highway, the White Horse Pike, creating traffic risks. Many poles were defective and unsafe, and many non-standard and hazardous conditions existed. Several difficult railroad and major highway crossings were involved. All of these potential accident conditions complicated the making of some 4,000 normal "climbs" and pulling down and reeling 7,000,000 feet of wire—all of which were accomplished without a single accident.

As in the case of the Pennsylvania Company, the 66 employees of Eastern Tel. & Tel. who joined the New Jersey Bell organization received full credit for their previous service as regards benefits, pensions, and similar matters.

CONSOLIDATION of the Keystone System was the largest job of its kind ever undertaken by the Bell Telephone Company of Pennsylvania, and was completed in remarkably short time, despite the many handicaps imposed by the wartime scarcity of facilities and manpower.

Thus, after many years, the era of duplicative telephone service in Philadelphia and in adjacent New Jersey has finally come to a close, in accordance with the long accepted principle that for two telephone systems to serve the same community is wasteful, expensive, and inefficient. Another milestone has been passed in the Bell System's effort to make it possible for "anyone anywhere to pick up a telephone and talk with anyone else anywhere else. . . ."